PRECAMBRIAN GEOLOGY OF THE BURNED MOUNTAIN-HOPEWELL LAKE AREA, RIO ARRIBA COUNTY, NEW MEXICO

by

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I would like to dedicate

this Thesis

to

my parents,

Eldon and Lillian Gibson,

who's support and continued encouragement

made the hard times easier and the

whole thesis possible,

Thank You.

Abstract

Precambrian rocks in the Burned Mountain-Hopewell Lake Area, northern Rio Arriba County, New Mexico are covered by a thin veneer of Tertiary and Quaternary rocks. The Precambrian rocks have been metamorphosed to the lower temperature range of low grade metamorphism and have undergone multiple periods of deformation. The first two periods of deformation resulted in tight to isoclinal folds and the third in a crenulation cleavage. The first set of folds trends N 30-40 W. The second set trends N 70-80 W and plunge from 10 to 45 degrees to the west. The late stage crenulation cleavage is widely spaced and trends N 20 W to N 20 E and dips from 50 to 90 degrees. The oldest rocks recognized in the area are a sequence of mafic schists, interpreted as metamorphosed mafic volcanics and volcaniclastic sediments. The Burned Mountain metarhyolite, interpreted as an ash-flow tuff, unconformably overlies these mafic rocks. Overlying and interbedded near the base, with the metarhyolite is a sequence of feldspathic metasediments, largely metasubarkoses, but also minor conglomeratic lenses. South of the NW trending Vallecitos Valley Fault, is a thick sequence of vitreous quartzites, tentatively interpreted as the youngest Precambrian rocks in the area.

During the second period of deformation a granodiorite sill (or sills) was intruded into the supracrustal sequence, developing a weak to moderate foliation and a lineation defined by knots of biotite. Very late in this same deformational episode the granite of Hopewell Lake intruded the supracrustals and the lineated granodiorite, but itself developed only a very weak foliation.

Whole-rock geochemical analyses of selected rocks from the study area allow a tentative classification of the mafic Moppin series rocks as subalkaline tholeiites. Two of the intrusive granodiorite bodies plot as trondhjemites on Barkers (1979) An-Or-Ab classifications diagram. The third intrusive plots as a granodiorite on this same diagram.

Hydrothermal sulfide replacement veins and gold-bearing quartz veins are common throughout the area, but were not examined closely in this study. The host rocks are exclusively Precambrian in age and the mineralization is pre-Tertiary.

The most likely tectonic setting for the Precambrian rocks in the study area and most consistent with other Precambrian terranes in northern New Mexico and southern Colorado is one of early extension, followed by compression. Either a back-arc basin or an aulacogen which has been compressed would be consistent with the observed geology in the northern Tusas Mountains.

ACKNOWLEDGMENTS

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INTRODUCTION

LOCATION

The study area is located in the Tusas Mountains approximately 20 miles west of Tres Piedras, New Mexico, on U.S. Highway 64 (Fig. 1). The area encompasses approximately 17 square miles in the Carson National Forest and on private land. It lies between north latitude 36 38′ and 36 44′ and west longitude 106 10′ and 106 17′ on portions of the Burned Mountain (7.5-min.) and Cebolla (15-min.) quadrangles. Elevations range from 9,000 to 10,200 feet.

PURPOSE

The purpose of this study was to map, describe, and determine the geological history of the Precambrian rocks exposed in the area outlined in Figure 1. Emphasis was placed on the Moppin series, Burned Mountain metarhyolite, and the subarkoses at the base of the Kiowa Mountain formation. The mapping is supplemented by petrographic and limited geochemical analyses. The major objectives of this study were:

1) to subdivide the Moppin series rocks on lithological and/or textural criteria;
2) to delineate and try to establish a source area for the Burned Mountain metarhyolite;

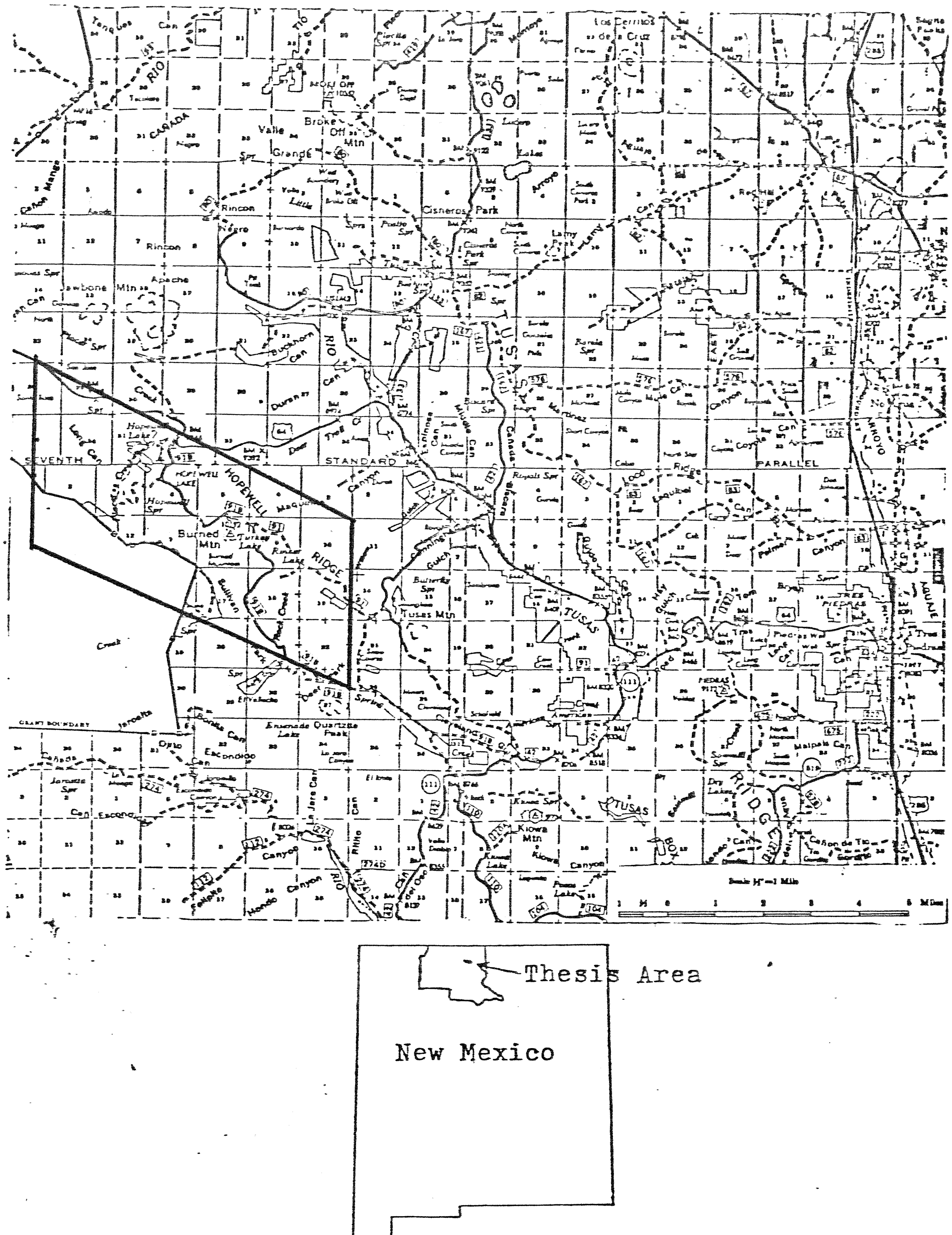


Figure 1

Location map of Thesis Area (in red). Map of New Mexico showing Rio Arriba County and Thesis Area.

3) to examine the stratigraphic relationships of the Moppin series, Burned Mountain metarhyolite, and the Kiowa subarkoses(feldspathic metasediments);
4) to define the Precambrian structural and metamorphic history of the area;
5) to speculate briefly on tectonic setting and similarities to other Proterozoic terranes in northern New Mexico and southern Colorado.

PREVIOUS WORK

The first general geological study of the Precambrian rocks in the area was made by Just (1937), who mapped from north of Jawbone Mountain to south of Ojo Caliente and named the major Precambrian units. Barker (1958) mapped the Las Tablas (15-min.) quadrangle, which has since been divided into 7.5-min. sheets, the northwest one being the Burned Mountain quadrangle. He redefined and renamed many of Just's units. Doney (1968) mapped the Cebolla quadrangle using Barker's units. Hutchinson (1968) mapped approximately 16 square miles in the vicinity of Burned Mountain as part of a Master's Thesis at Colorado School of Mines. In 1968 Bingler compiled a map of Rio Arriba County after completing a map of the La Madera (7.5-min.) quadrangle (SE of the study area) in 1963. McLeroy (1970) subdivided part of the Moppin Series in the vicinity of Tusas Mountain as part of a detailed study of a banded iron formation. Kent (1980) mapped approximately 15 square miles immediately adjacent to the southeastern border of this study area as part of a Master's Thesis at New Mexico Institute of Mining and Technology. Other work reflecting aspects of mineralization, Precambrian geology, geochronology, and/or geochemistry in the Tusas Mountains includes: Barker (1969b); Barker and Friedman (1974); Benjovsky (1945); Bertholf (1960); Gressens (1975, 1976); Gressens and Stensrud (1974a, 1974b); Hovorka (1978); Lindgren and others (1910); Long (1972); Jahns (1946).

METHODS OF INVESTIGATION

The author spent approximately four months mapping the study area at a scale of 1:12000 on maps enlarged from U.S.G.S. quadrangle maps. Pace and compass traverses were used in areas of heavy foliation and a Thommen altimeter was used on a limited basis.

Fifty-six of ninety-one rock samples collected were selected for the making of thin sections. They were examined petrographicaly using a Zeiss polarizing microscope. Plagioclase compositions were determined using the Michel-Levy method (Kerr, 1959). Ten whole rock geochemical analyses were obtained by atomic absorption methods under the supervision of Lynn Brandvold in the labs of the New Mexico Bureau of Mines and Mineral Resources.

The New Mexico Institute of Mining and Technology's Dec20 computer system was used to prepare, edit, and print this manuscript. It was also used to compute CIPW norms from the geochemical analyses.

PHANEROZOIC GEOLOGY

INTRODUCTION

The study area contains only Precambrian, Tertiary, and Quaternary rocks. If rocks of any other age were ever deposited they were removed by subsequent uplift and erosion. The area lies on the NW-SE trending Brazos uplift which extends from near the Colorado border south to Ojo Caliente and from Tierra Amarilla east to Tres Piedras. It is flanked by the Chama-San Juan basin to the west and the Rio Grande Rift to the east (see Fig. 2). The information that follows comes principally from Doney (1968), Bingler (1965), Barker (1958), Muehlberger (1960, 1967, 1968), and Woodward (1974).

PALEOZOIC ERA

The area of this study must have been positive during most if not all of the Paleozoic. Outcrops of Paleozoic rocks are absent in the general area until well into the Pennsylvanian. In the adjacent Cebolla quadrangle, unnamed Pennsylvanian marine arkosic sandstones, siltstones, and limestones thin onto the Brazos uplift north of Tierra Amarilla along Chavez Canyon (Muehlberger, 1967), suggesting the area of this study was high through Pennsylvanian time. There is no evidence that Permian rocks were deposited in the area.

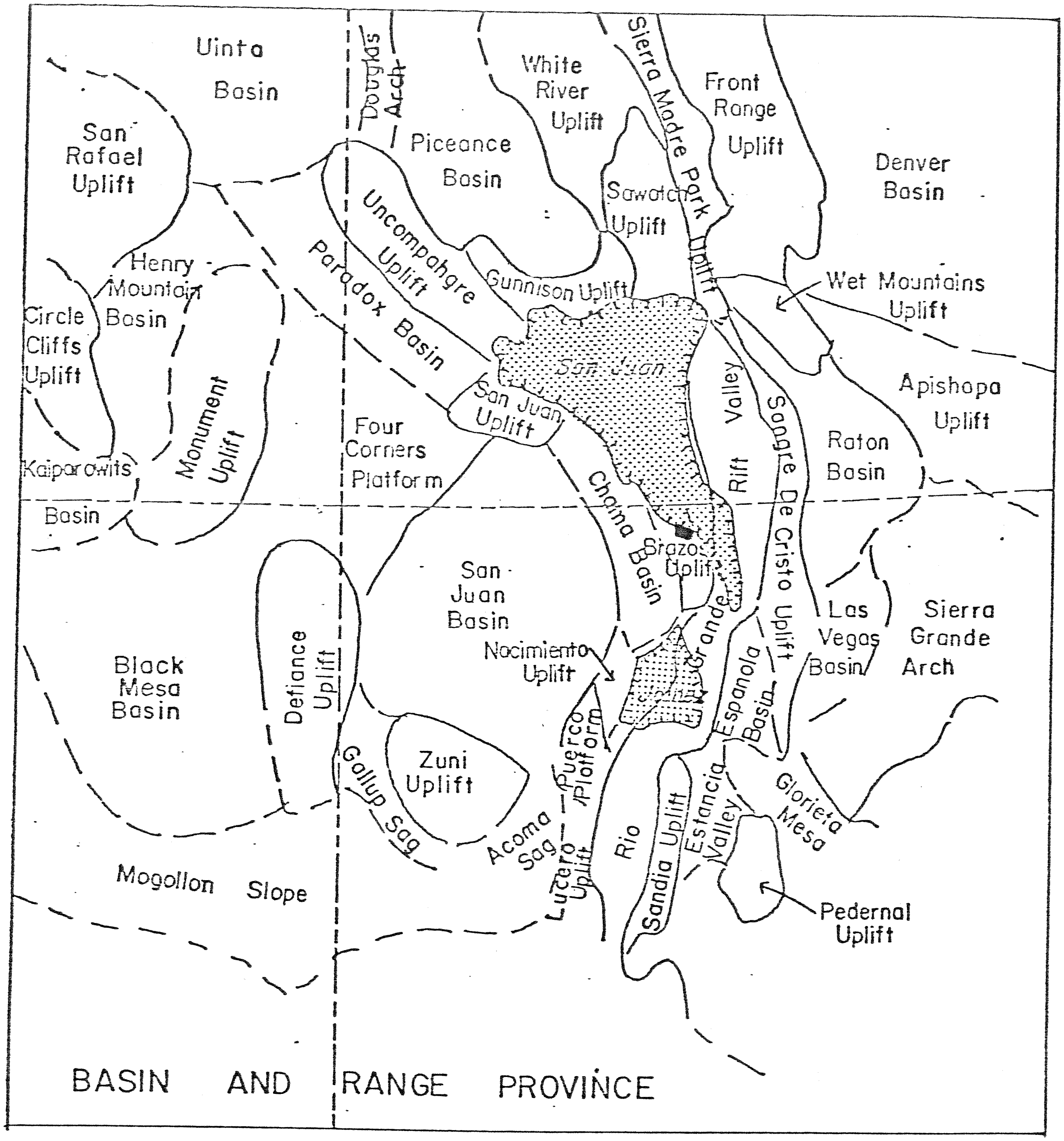


Figure 2

Map of Geologic Provinces in Four Corners Region. Thesis area in red (after Gross, 1972).

MESOZOIC ERA

Uplift and erosion lasted well into the Triassic Period as evidenced by the disconformity or unconformity between the Precambrian-Pennsylvanian-Permian and the Triassic Chinle east of the study area. Fossils of land vertebrates in the Chinle, of a type associated with alluvial flood plains, suggest the Tusas Mountains were still a positive land area through the Triassic (Doney, 1968). The Jurassic Entrada formation unconformably overlies the Chinle indicating uplift at that time. The Todilto and Morrison formations, also of Jurassic age, seem to overlie the Entrada conformably. A period of erosion ensued at the end of the Jurassic and lasted until the transgression of the Cretaceous seas with their basal Dakota formation, which lies directly on the Precambrian in the Brazos Peak quadrangle to the northwest (Muehlberger, 1968). The Cretaceous seas continued their southeastward migration depositing the Mancos shale and possibly the Mesaverde Group, but it is impossible to say if any Mesozoic rocks were deposited in the study area because of subsequent erosion during and following the Laramide orogeny. The San Juan basin formed as the San Juan and Tusas Mountains were uplifted along a line coincident to their present positions.

CENOZOIC ERA

The Laramide orogeny with its accompanying uplift and deposition of volcanic and sedimentary rocks continued through the Eocene. The area of this study continued as a topographical high.

The Oligocene-Miocene El Rito conglomerate (Barker, 1958) was deposited across the area by streams and is the basal unit overlying the Precambrian in the study area. It is composed of well-cemented Precambrian pebbles, gravels, and boulders (see Fig. 3). It crops out along Long Canyon and along the tributaries to Placer Creek in Eureka Canyon. The Ritito conglomerate (Barker, 1958) overlies the El Rito disconformably and is made up of Precambrian pebbles, gravels,and boulders, but has a poorly sorted and cemented matrix of quartz sand. The disconformity is attributed to rifting along the Rio Grande to the east (Doney, 1968). The Ritito conglomerate can be found across most of the area, north of the Vallecitos Valley.

Unconformably overlying the Ritito are the poorly sorted sandstones, poorly cemented conglomerates, tuffaceous graywackes, and local basalts of the Los Pinos formation. Isolated boulders of the Treasure Mountain rhyolite are found in this unit, suggesting the rhyolite may have not reached this far south.

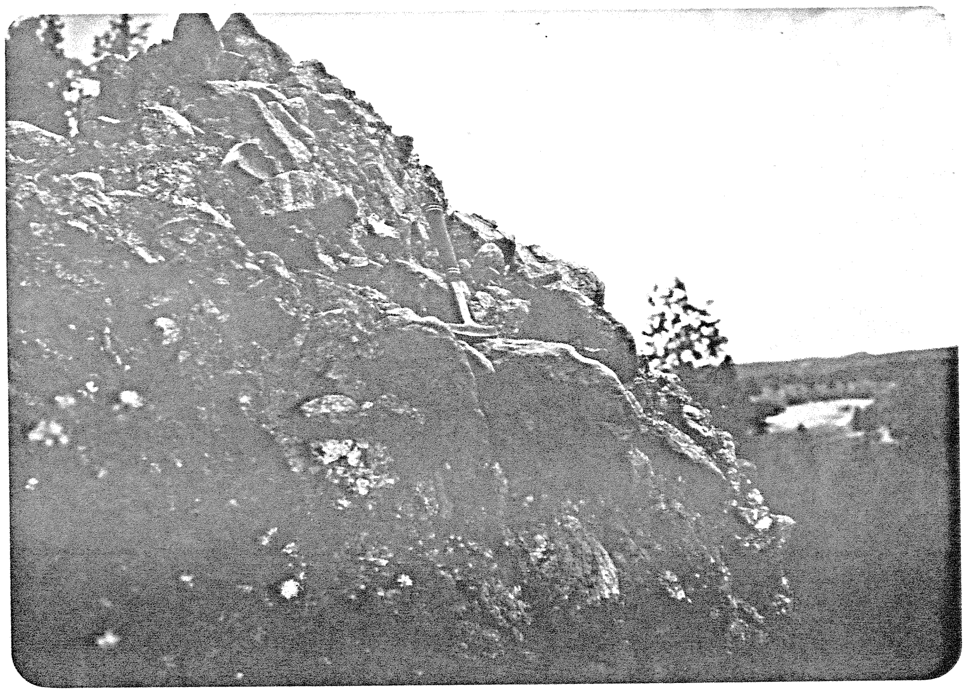


Figure 3

Basal Tertiary Unit, the El Rito Conglomerate, picture taken of outcrop west of Long Canyon in section 36 T.29N. R.6E.

Quaternary alluvium is found along all stream beds in the area and colluvium is abundant on many slopes, covering much of the area's Precambrian outcrops. Glacial deposits are present in and around the study area. Smith (1933) recognized two periods of glaclation in the area. The oldest is represented by the Quaternary glacial till formed by a piedmont rather than a valley glacier. This till was deposited on a peneplain of early Pleistocene age. Erratics of quartzites up to 5 meters long can be found. Landslides of this losely consolidated till have covered many of the slopes where Precambrian rocks should outcrop. The second glaciation is represented by U-shaped and hanging valleys.

Quaternary (?) boulder fields in the area contain large rounded boulders of the adjacent Precambrian rocks, usually quartzite. The origin of and the relationships to other Quaternary rocks is not known.

PRECAMBRIAN GEOLOGY

INTRODUCTION

ROCK NOMENCLATURE

The most commonly used names for rock units in the Tusas Mountains were proposed by Barker (1958) who renamed many of the units first described by Just in 1937. Table 1 is a comparison of the rock names used by Just, by Barker, and those used in this study. Kent (1980) separated the Maquinita granodiorite in the area east of this study into a lineated granodiorite and the granodiorite of Spring Creek.

Many of the original textures and structures are preserved in the Precambrian Rocks of the study area and where there is little doubt as to the original rock type, original igneous or sedimentary names are used in lieu of metamorphic ones (examples; metarhyolite instead felsic schist, and metasubarkose instead of feldspathic metasediment. Metamorphic names are used when the original rock type is not obvious or there is some doubt.

REGIONAL PRECAMBRIAN GEOLOGY

The map area is situated along the crest of the Brazos uplift. Precambrian rocks are exposed along the axis of this high from the Colorado border where they crop out from beneath the Tertiary volcanic rocks of the San Juan volcanic

Table 1

Precambrian Rock Nomenclature
Northern Tusas Mountains

Just (1937)	Barker (1958)	This Study
Tusas Granite	Maquinita Granodiorite	Lineated Granodiorite
	Tres Piedras Granite	Granite of Hopewell Lake
Ortega Quartzite	Kiowa Mountain Formation	Feldspathic Metasediments
	Ortega Quartzite	Vitreous Quartzite
Vallecitos Rhyolite	Burned Mountain metarhyolite	Burned Mountain metarhyolite
Hopewell Series	Moppin MetaVolcanic Series	Moppin Series

field to Ojo Caliente where sediments of the Rio Grande rift onlap the uplift. Precambrian rocks in this study area, crop out best along streambeds and canyons but outcrops can be found almost anywhere. Precambrian rocks crop out over approximately 10 percent of the area.

Precambrian rocks described in this study have been subjected to at least two periods of major deformation. Low grade metamorphism is evidenced by the mineral assemblage chlorite-albite-muscovite in the mafic volcanics of the Moppin series (Winkler, 1979). Metamorphism of up to lower amphibolite facies (oligoclase, staurolite, kyanite, garnet) is developed to the southeast and northwest of the study area, indicating an increase in metamorphic grade to the northwest and southeast.

Trondhjemites that intrude the Moppin series north of the present study area, have been dated at approximately 1.7 b.y. (Barker and others, 1974). Syntectonic granodiorites are present throughout the region. Younger granites intrude both the granodiorites and the supracrustal rocks. Late quartz veins cut all of the rocks in the area and pegmatites appear to the southeast and become more numerous as one progresses in that direction.

Mineralization in the form of quartz and replacement veins occurred sometime after intrusion of the last granites. Weathering of the mineralized veins resulted in placer deposits along some stream valleys in the area. The mineralization is pre-Tertiary in age, as the lower most Tertiary unit contains cobbles and boulders of mineralized Precambrian rock.

GENERAL STRATIGRAPHY OF THE BURNED MOUNTAIN AREA

Field relations suggest that the mafic rocks of the Moppin series predate all other rocks in the study area. They are unconformably overlain by Burned Mountain metarhyolite and/or feldspathic metasediments with pebbly horizons near their base.

The Moppin series is composed of mostly mafic rocks, mainly now quartz-muscovite-chlorite schists that contain thin (1 to 5 mm) lenses of calcite, epidote, and sericite. Schists containing megacrysts (probably relict phenocrysts) are present but not common. Approximately eighty-five percent of the Moppin is made up of these mafic schists. Ten percent of the rock in the Moppin series is felsic schist. A diabasic textured mafic unit and a conglomeratic unit with phyllitic clasts in a matrix of muscovite and chlorite each comprise approximately 2 to 3 percent of the Moppin series in the study area.

Overlying the Moppin series is a porphyritic felsic schist with relict eutaxitic texture and inclusions of rounded chert pebbles, here called the Burned Mountain metarhyolite. The metarhyolite is locally interbedded with pebbly metasubarkoses. Although it typically underlies such rocks. This unit can be traced more-or-less continuously along strike over much of the study area, varying in thickness from 10 to 100 meters. Pebbles and cobbles of this distinctive metarhyolite have been found in the overlying metasedimentary conglomerate lenses although they are not abundant.

Also overlying the Moppin series, is some places directly, are a series of feldspathic metasediments of which subarkoses comprise approximately 80 percent. Pebble conglomerates with quartz, chert, rare mafic clasts from the Moppin, phyllitic clasts, and felsic cobbles from the Burned Mountain metarhyolite make up approximately 15 percent of the feldspathic metasediments. Near the base of the subarkosic unit is a phyllitic unit and banded quartzite unit which together make up 1 to 4 percent of the feldspathic metasediments. Minor amounts of microcline-muscovite-quartz schist are present near the base. The amount of quartz in a sample of feldspathic metasediment increases as you go stratigraphicaly upwards in the sequence. Stratigraphic facing can be determined in this unit by graded bedding and in places by crossbedding.

The stratigraphically youngest Precambrian unit in the map area is a vitreous quartzite (interpreted by Barker (1958) as being both older and younger, elsewhere in the Tusas Mountains), characterized by well-developed crossbedding and forming rounded, prominent outcrops. The quartzite is separated in this study area from the subarkoses by the northwest-trending Vallecitos Valley fault which runs the length of the area.

Two types of intrusive rocks cut the supracrustal succession in the northern Tusas Mountains, syntectonic granodiorites and mainly post tectonic granites. The granodiorites were collectively termed the Maquinita granodiorite by Barker (1958), although the present study has identified two textural and compositional varieties. Barker's Tres Piedras granite is represented locally by a small pluton that crops out around Hopewell Lake and in this study called the granite of Hopewell Lake.

STRATIGRAPHY

MOPPIN SERIES

Field relationships in the study area indicate that the oldest rocks are the Moppin series. Five distinct lithologies can be recognized within the Moppin on the basis of mineralogical and/or textural differences, and three are abundant and/or continuous enough to be mapped as separate units in this study. They are a quartz-muscovite-chlorite schist (80 percent of Moppin), a felsic schist (10 percent of Moppin), and a mafic-conglomeratic schist (5 percent of Moppin). The base of the Moppin series is nowhere exposed. The best exposures of the series are in the southeastern portion of the field area (see Plate 1). Near the intrusives (granodiorite and granite) the Moppin series becomes undividable because of appearance of plagioclase and quartz crystals.

Quartz-muscovite-chlorite schist, the most common rock type of the Moppin series, is dark green to greenish-gray, well-foliated, and crops out as low knolls. It is most abundant in the eastern portions of the field area. In some localities, the rock contains, sheared knots of muscovite and calcite. Megacrysts (relict phenocrysts ?) of plagioclase are common and have chlorite and muscovite wraped around them. Magnetite euhedra up to 2 mm are common as is iron staining. The rock breaks along cleavage planes.

The plagioclase megacrysts where not altered or crushed beyond recognition range up to 1.5 cm in length. This rock is composed of quartz, muscovite, chlorite, sodic-plagioclase, and calcite with minor epidote/clinozoisite and actinolite/tremolite.

These rocks were probably emplaced as mafic flows or volcaniclastic sediments derived from the flows. Lack of distinct primary igneous or sedimentary features make a quantitative estimate of flow versus metasediment difficult. Megacryst-bearing mafic rock comprises 60 to 75 percent of the quartz-muscovite-chlorite schist, whereas megacryst-free schist comprises 25 to 40 percent.

The second most abundant rock type in the Moppin series is a felsic schist. It occurs as a single stratigraphic horizon within the mafic schists. The felsic schist's exact stratigraphic position within the Moppin series is difficult to determine due to lack of stratigraphic markers and possible folding. It is found in the northernmost exposed portions of the Moppin, where it is very poorly exposed, occurring mainly as float.

The felsic schist has phenocrysts of rounded blue quartz (2 to 5 mm) in an aphanitic groundmass. It is well to moderately well-foliated and breaks along these cleavage planes. This schist is compositionaly layered with mainly quartz, potassium feldspar, and chlorite crystals. Knots of chlorite are stretched in the plane of foliation and strongly altered relict plagioclase megacrysts are very rare. The aphanitic matrix is composed largely of quartz, potassium feldspar, and muscovite with minor epidote and albite. Magnetite and hematite are common accessory minerals.

The author's tentative interpretation of this rock is that it is a reworked tuff, possibly a distal facies of the Burned Mountain metarhyolite emplaced in the Moppin series tectonicaly. No relict glass shard remain however. The chlorite and plagioclase could be detritus from underling mafic rocks or altered products of original minerals.

The third and smallest mappable unit in the Moppin series is a conglomeratic mafic schist approximately 3 meters thick (see Fig. 4). This well-foliated rock crops out along Rock Creek in section 16 T.28E. R.7E. as rounded-elongate knolls. It breaks along the well developed foliation planes. Fragments of well-foliated light-gray phyllite are contained in a matrix of dark-green to greenish-gray schist. The fragments are flattened and stretched and define a strong lineation in the plane of foliation. Only phyllite fragments are found in this unit and sorting is poor. These fragments comprise approximately 40 percent of the rock and range from a few millimeters up to 12 cm in length. The matrix is composed of quartz, muscovite, chlorite, and minor albite and epidote. The phyllite fragments are made up of mainly quartz and muscovite with only minor chlorite and epidote.

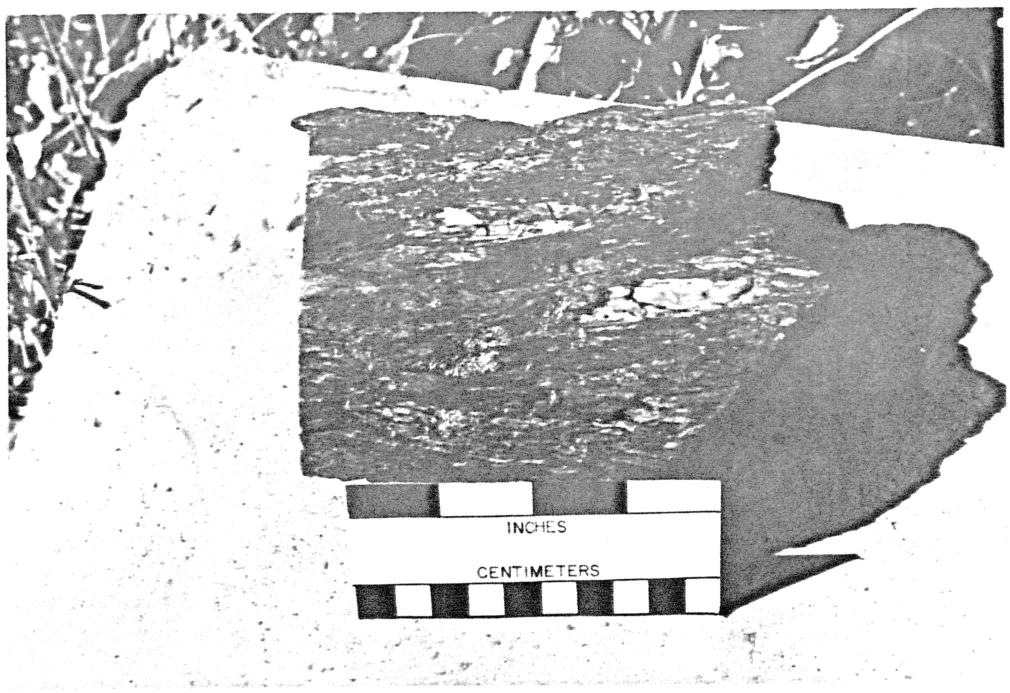


Figure 4

Photograph of Moppin conglomeratic mafic schist
From along Rock Creek in section 16 T.28E. R.7E.

The fragments (pebbles ?) in this metaconglomerate probably originated by high energy erosion of a slightly more silicic sediment than the average Moppin volcaniclastic sediment. The source of the phyllitic pebbles (probably originaly a mudstone or siltstone) must have been fairly near or the pebbles would have disintegrated into sand or mud. However no phyllitic unit similar to the pebbles was observed in the study area.

Two additional rock types are present in the Moppin series, but are not continuous or abundant enough to map as separate units. The first is a massive to weakly foliated, porphyritic dark-green to grayish rock with relict diabasic texture. It crops out in sparse discontinuous low-rounded knolls. This rock breaks along its very weak foliation planes. The discontinuous outcrop pattern and lack of marker horizons in the surrounding greenschists make contact relationships difficult to interpret, but this rock is tentatively thought to be intrusive. This schist is usually badly altered and/or weathered. It is composed of sodic-plagioclase, chlorite, and quartz with minor epidote/clinozoisite. Magnetite and hematite are common accessory minerals.

This rock was probably emplaced late in the Moppin series history as shallow diabasic intrusives of the same material that was being extruded onto the surface as flows.

The second minor unit, too small to map, occurs near the top of the Moppin series. It is a well-foliated chlorite-quartz-muscovite schist. It is found as float or as rare low, angular outcrops. The rock breaks along cleavage planes and contains rare magnetite octahedra (1 to 2 mm). This schist's constituents are all fine grained and approximately equal in grain size. Most likely the rock is of sedimentary origin, such as a silt or shale deposited in a fairly low energy environment such as a flood-plain or lake.

BURNED MOUNTAIN METARHYOLITE

Overlying the Moppin Series is a porphyritic felsic schist, in this report called the Burned Mountain metarhyolite. It is interbedded with pebble conglomerates and feldspathic metasediments and crops out across the entire study area. Excellent outcrops can be seen on the south side of Burned Mountain (Sec. 8, T.28N. R.7E.) and along Sheep Gulch (Sec. 22, T.28N. R.7E.). Barker and Friedman (1974) report a U/Pb Zircon age of 1715 to 1765 for this rock.

The Burned Mountain metarhyolite and/or feldspathic metasediments apparently overly the Moppin series with a slight angular unconformity, although this contact was never observed in the present study area. Some lines of evidence that support such an interpretation are:

1) Truncation of Moppin series stratigraphy against the contact (Kent, 1980). Lack of any recognizable bedding near the top of the Moppin in this study area prevented the author from making the same interpretation;
2) Pebble conglomerates interbedded with the Burned Mountain metarhyolite suggest uplift and erosion nearby, during deposition of the metarhyolite, although no Moppin series pebbles have been identified.

Multiple outcrops of metarhyolite are present along Sheep Gulch and Rock Creek where they are separated by arkosic sediments and pebble conglomerates. These horizons, which range from 10 to 100 meters in thickness are interpreted as a single horizon repeated by folding (see structure section and Plate 1).

Burned Mountain metarhyolite outcrops displays bold, brick red to grayish-pink, massive to weakly foliated weathered surfaces. The rock breaks with uneven surfaces and is characterized by an aphanitic groundmass with 40 percent relic phenocrysts of rounded blue quartz and subhedral potassium feldspar in roughly equal amounts. Light-gray or light-red phenocryst-bearing, aphanitic lenses are interpreted as flattened pumice fragments. Inclusions of rounded red-chert pebbles (2 to 5 cm) are rarely present near the base (see Fig. 5). This rock is composed of quartz, microcline, muscovite, with minor plagioclase. Magnetite and apatite are common as accessory minerals.

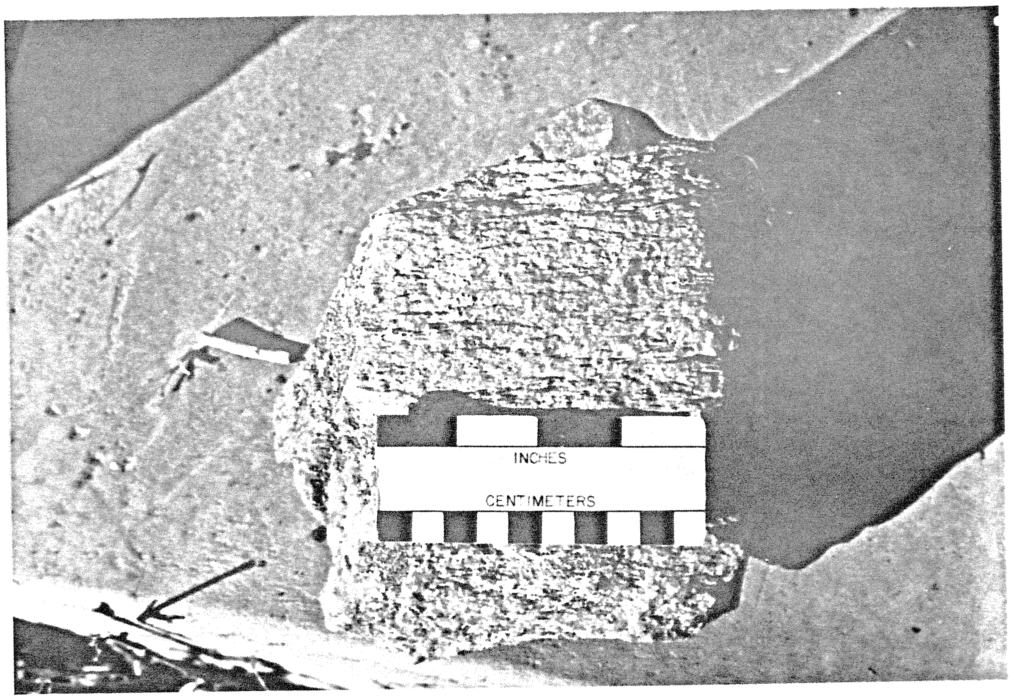


Figure 5

Rounded red chert cobble from near the base of the Burned Mountain metarhyolite. From south side of Burned Mountain, section 8, T.28N. R.7E.

This metarhyolite is interpreted in the area of this report to be extrusive, probably an ash-flow tuff. The following evidence is consistent with an extrusive, ash-flow origin for the Burned Mountain metarhyolite:

1) There is no evidence in the study area or nearby that the Burned Mountain metarhyolite has intrusive contacts as previously reported (Barker, 1958; Hutchinson, 1968).
2) The limited but consistent stratigraphic position of the unit is consistent with an extrusive mode of emplacement.
3) Extensive lateral continuation along strike is common for ash-flow sheets, but rare in silicic flows.
4) Pebble and cobbles of the metarhyolite in the overlying pebble conglomerates suggest the unit was available to weathering soon after emplacement.
5) Eutaxitic textures are not uncommon and are well exposed on the south side of Burned Mountain (see Fig. 6).

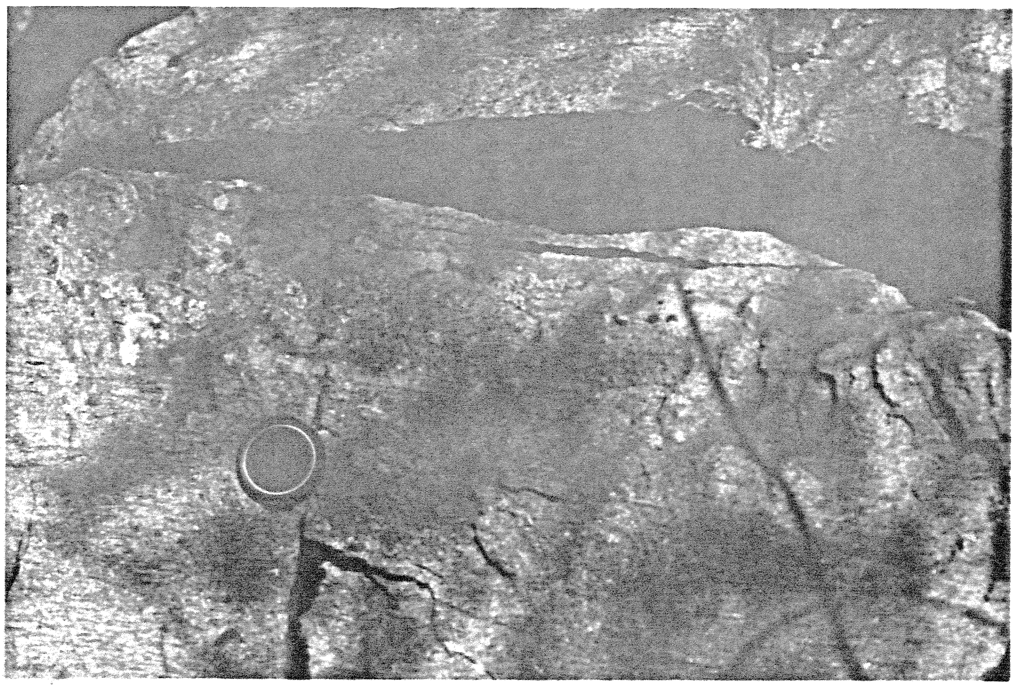


Figure 6

Pumice fragments (lighter pink lenses) in the Burned Mountain metarhyolite. From south side of Burned Mountain, section 8, T.28N. R.7E.

FELDSPATHIC METASEDIMENTS

Interbedded with and overlying the Burned Mountain metarhyolite is a sequence of feldspathic metasediments. Five distinct units are recognized, but only two are abundant and/or continuous enough to be distinguished at the present map scale. They are the metasubarkoses and metaconglomerates.

A massive to foliated metasubarkose (as classified by Pettijohn and others, 1973) crops out across the entire study area. It comprises approximately 80 percent of the area mapped as feldspathic metasediment. It forms massive, rounded to angular knobs and knolls and exhibits graded-bedding and crossbedding (see Fig. 7). This rock weathers dark-gray to gray and breaks along foliation planes when they are present. It is light-gray on a freshly broken surface. Bedding ranges from a few centimeters up to a meter in thickness and is both lenticular and tabular. Crossbedding is enhanced by the concentration of magnetite grains on bedding planes. Graded-bedding is not uncommon with quartz grains ranging from 1 mm up to 2 cm in diameter. This rock is composed largely of quartz with muscovite and potassium feldspar being common in minor amounts. Epidote, magnetite, and hematite are common accessory minerals and together may make up as much as 5 percent of the rock. Average grain size is approximately 1 to 2 mm, but a wide range is common.

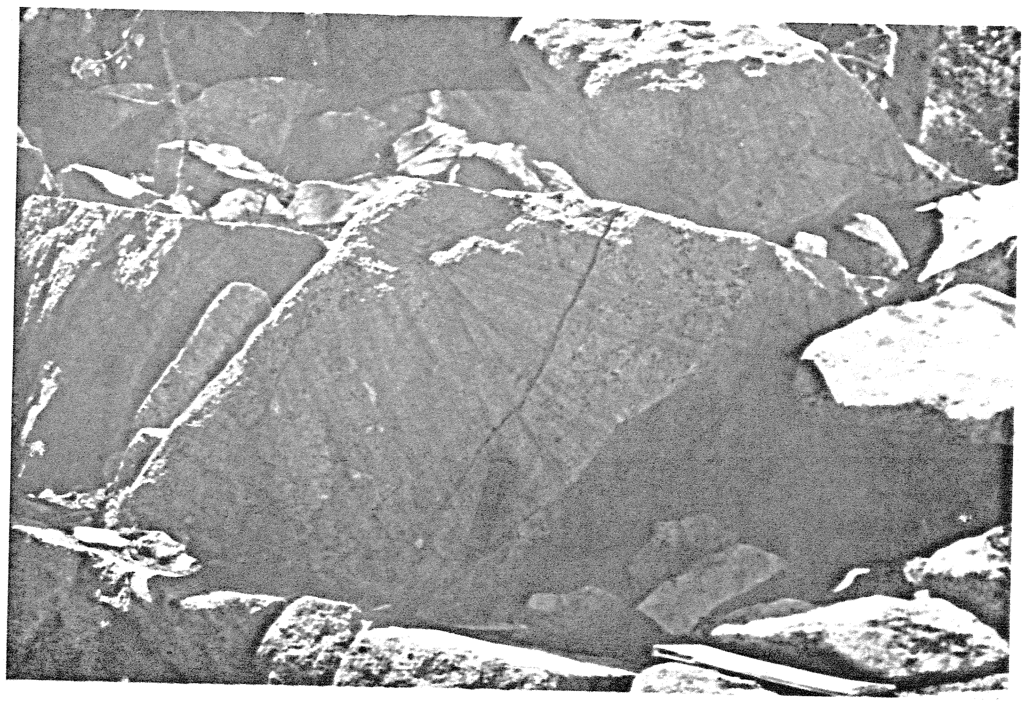


Figure 7

Crossbedding in the metasubarkose from outcrop on southwest flank of Burned Mountain, section 8, T.28N. R.7E.

Near the base of the metasubarkoses, 10 to 20 meter long and 5 to 10 meter thick, discontinuous lenses of pebble conglomerates are common and make up as much as 15 percent of the feldspathic metasedimentary sequence. The pebble conglomerate crops out in much the same fashion as the metasubarkoses. The cobbles and pebbles are milky quartz, chert, felsic schist, and phyllite. The phyllite pebbles are stretched and flattened in the plain of foliation and the chert and quartz pebbles and cobbles are subrounded to angular and have not been deformed. The pebbles and cobbles occur in varying amounts in different lenses. Phyllite, quartz, and chert are much more common than the other lithologies. The flattening and stretching of the phyllite fragments results in a well-developed lineation (Fig. 8). The matrix material of these metaconglomerate lenses is the metasubarkosic material found in the surrounding rock.

Thin sections of phyllite fragments perpendicular to foliation exhibit two foliations. These fragments seem to preserve an earlier deformational episode better than the metasubarkosic matrix.

Both the metasubarkoses and the metaconglomerate lenses are interpreted as a sequence of sediments deposited on the flanks of a rapidly rising uplift. Rapid erosion of the Burned Mountain metarhyolite and the Moppin series is

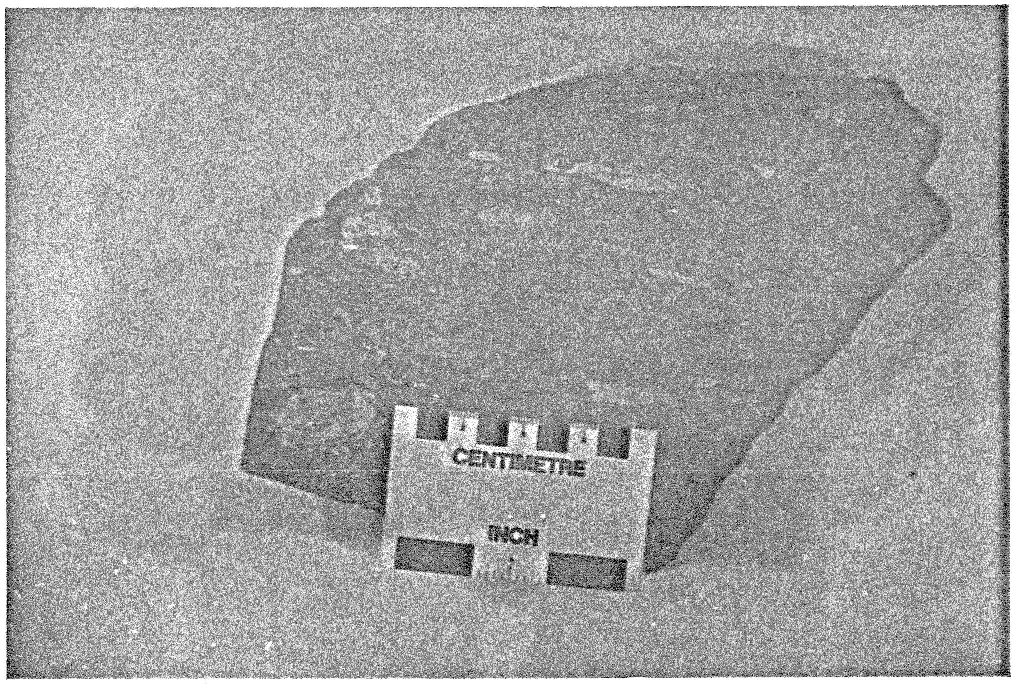


Figure 8

Subarkosic metaconglomerate (stretched pebble conglomerate) from Rock Creek Drainage, section 9, T.28N R.7E.

evident by the conglomeratic fragments. Streams of moderately high energy picked up fragments of these and other rock types and deposited them fairly soon as energy levels dropped. Graded-bedding and crossbedding could both occur in such an environment.

The distinct compositional disparity between the feldspathic metasediments and the underlying mafic Moppin series rocks (marked by the Burned Mountain metarhyolite) must somehow be explained. It does not seem possible that erosion of the metarhyolite, at least of the thickness observed in the study area, could supply all the material now found in the feldspathic metasediments. If however, the area of this report lies along the distal edge of a large felsic eruptive center (represented here by the Burned Mountain metarhyolite) the material for the feldspathic metasediments could have been derived from the weathering of felsic volcanics nearer the center of volcanic activity.

Interbedded with the metasubarkoses and conglomeratic lenses are three additional rock types that are not abundant or continuous enough to map at the present scale. They are a banded quartzite, a quartz-muscovite schist, and a microcline-muscovite-quartz schist. These minor rock types are best exposed east of Rock Creek in section 9, T.28N. R.7E.

The banded quartzite and the quartz-muscovite schist are always found associated with each other. Neither ever attains a thickness of more than 1 meter and both are fine-grained. The banded quartzite is characterized by thinly banded laminae of quartz enhanced by red, brown, and/or gray fine grained minerals, probably some combination of magnetite and hematite. The quartz-muscovite schist has a near phyllitic luster and is well-foliated. The microcline-muscovite-quartz schist is fine grained, minor in extent, found near the base of the feldspathic metasediment sequence, and occurs as massive to moderately foliated, gray to brownish-gray outcrops.

The banded-quartzite and the quartz-muscovite schist might possibly represent localized areas where fine grained (indicating low energy environment) sedimentary material was deposited, such as small lakes or flood-plains. The microcline-muscovite-quartz schist would be expected near the base of a feldspathic sedimentary pile that becomes increasingly quartz rich as you go up stratigraphicaly.

VITREOUS QUARTZITES

In fault contact with the feldspathic metasediments is a sequence of purplish-gray to blue-gray, poorly foliated, well crossbedded, vitreous quartzites. They crop out as bold, smooth, massive, angular to rounded knolls and bluffs. The crossbedding is enhanced by magnetite grain concentrations on the fore-set bedding planes. Graded bedding is not uncommon. The rock is composed almost entirely of quartz with minor magnetite.

The relationship of the vitreous quartzites to the feldspathic metasediments is not entirely clear. West of the study area, in the Brazos Box, the metasubarkoses appear to grade stratigraphically upward into relatively pure quartzites. Although these two rock types display a fault contact (or one covered by alluvium or colluvium) everywhere in the present study area, there is still some evidence that supports such a gradational relationship:

1) The quartz content of the metasubarkoses increases in a stratigraphic upward direction.
2) Graded bedding and crossbedding in both the quartzites and the feldspathic sediments indicate stratigraphic tops facing to the south.
3) Minor interbedded metasubarkoses can be found with the quartzites in sections 1 and 2, T.28N. R.7E.;
4) Nowhere in the study area are the quartzites intruded by any of the granitic intrusives.

This evidence is consistent with the quartzites being younger and possibly gradational with the metasubarkoses.

INTRUSIVE ROCKS

LINEATED GRANODIORITE (MAQUINITA GRANODIORITE)

The oldest intrusive rock in the area is a moderately to strongly foliated granodiorite. It intrudes the Moppin series, the Burned Mountain metarhyolite, and the feldspathic metasediments. Barker (1958) named it the Maquinita granodiorite for exposures along Maquinita Canyon in sections 3 and 4, T.28N. R.7E. A Rubidium-strontium age of 1675 to 1715 m.y. has been reported by Barker and Friedman (1974) for this rock.

The granodiorite is homogeneous, gray to dark-gray, and strongly lineated. The lineation and foliation are defined by the distribution and orientation of biotite in .5 to 2 cm knots. Contacts with the surrounding rocks are both sharp and gradational and everywhere parallel foliation. Contacts are commonoly characterized by the development of a "breccia zone" of country rock in a granodiorite matrix which may be as much as 150 meters wide. The granodiorite is sometimes green near the contact, indicating contamination by Moppin series rocks which have been assimilated by the intrusive. The greenschists near the contact are altered by fluids from the granodiorite making their identification difficult. Xenoliths of greenschist are common and range from a few centimeters up to 100's of meters in length near the contact.

GRANODIORITE OF SPRING CREEK

The granodiorite of Spring Creek is distinguished from the lineated granodiorite by the presence of prominent blue, rounded, quartz phenocrysts, its reddish-pink color, and the rarity of biotite knots. Kent (1980) first recognized this rock in an area immediately east of this study area.

This granodiorite is moderately to strongly foliated. The best exposures are along the middle fork of Rock Creek (NW 1/4 of Sec. 15, T.28N. R.7E.). Inclusions of Moppin series rocks are uncommon, but do not reach the dimensions (5 to 10 cm) found in the lineated granodiorite. Contacts with surrounding rocks generally parallel foliation and are both sharp and gradational as in the lineated granodiorite, but no "breccia zone" is developed. Contacts with the lineated granodiorite are gradational with biotite gradually increasing as the quartz phenocrysts disappear.

Kent (oral communication 1980) has suggested the granodiorite of Spring Creek may be a less deformed version of the lineated granodiorite. However other rocks in the study area and to the southeast do not suggest a decrease of stress in that direction. A greater stress in the lineated granodiorite could have recrystallized the quartz phenocrysts into matrix quartz (Spry, 1979). The lack of biotite knots still must be explained. Other interpretations are that this rock could possibly represent a slightly different, biotite poor phase of granodiorite intrusion, that, without the biotite did not develop a lineation, or that it may be a slightly younger phase, or both.

GRANITE OF HOPEWELL LAKE (TRES PIEDRAS GRANITE)

This rock was mapped as a part of a pluton of the Tres Piedras granite by Barker (1958). In this report it is called the granite of Hopewell Lake for exposures on a hill northeast of the lake and for dikes and sills in Eureka Canyon below the lake. The pluton is exposed over approximately one square mile. It differs from the Tusas Mountain Pluton of the Tres Piedras granite in that it is more foliated and contains numerous xenoliths of Moppin series rocks.

The granite of Hopewell Lake is a medium-grained, porphyritic granite whose contacts are sharp and discordant to a weakly developed foliation (See Fig. 9). It intrudes the Maquinita granodiorite (this contact is not exposed except in Eureka Canyon where alteration associated with mineralization makes its recognition difficult), the feldspathic sediments, and the Moppin series. Weathered granite is pink, flesh-colored, or reddish-orange and exhibits quartz phenocrysts standing in relief.

Figure 9

Photograph of Undivided Moppin and Granite of Hopewell Lake
From hill east of Lake, in section 32, T.29N. R.7E.

STRUCTURE AND METAMORPHISM

STRUCTURE

GENERAL STATEMENT

The study area is located along the crest of the Brazos uplift (Fig. 10). This uplift is bounded on the east by the Chama basin and on the south and east by the Rio Grande rift (Woodward, 1974). The uplift is dominated by northwest-trending faults some of which were downthrown to the east during Laramide time and were later downthrown to the west during late Tertiary (Muehlberger, 1960). The core of the uplift consists of Precambrian rocks overlain by a thin veneer of Tertiary volcanics and sediments.

Precambrian rocks in the area of this study are more complexly deformed than was originally thought. Just, (1937) reported one period of deformation; Barker, (1958) reported one period of deformation; and Hutchinson, (1968) reported one period of deformation and a late stage slip cleavage). Bingler (1965), however, does report three periods of deformation to the south of this study area in the La Madera quadrangle.

The Precambrian rocks in the northern Tusas Mountains have been folded at least twice, and as mentioned above, possibly as many as three times. They are poorly to well-foliated and some rocks contain two foliations. A lack

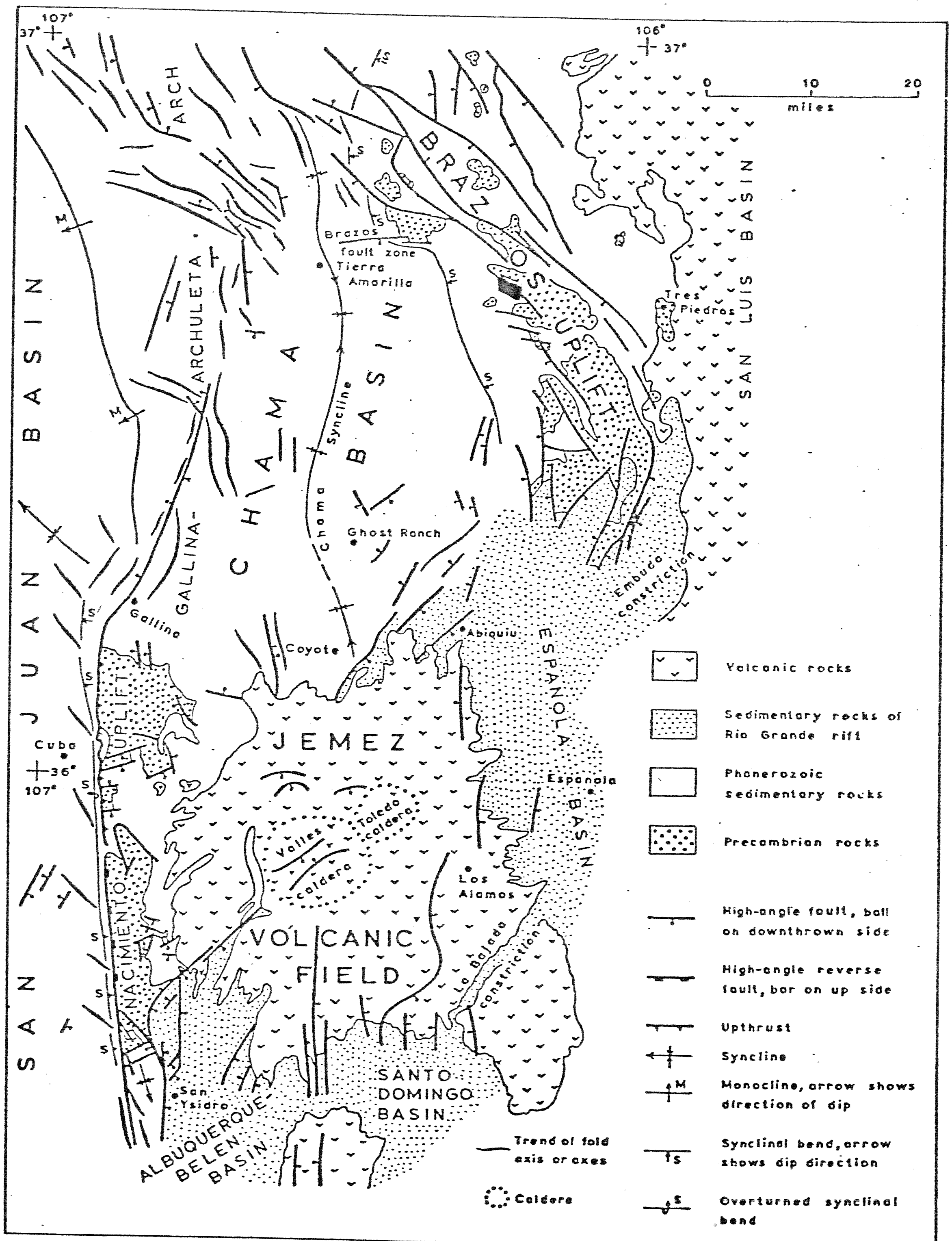


Figure 10

Tectonic Map of North-Centeral New Mexico, with study area in red (after Woodward, 1974).

of continuous primary stratigraphic indicators in the Moppin greenschists make structural interpretation of areas where they crop out difficult. The feldspathic metasediments and the Burned Mountain metarhyolite are both useful in structural interpretations. The metasediments contain stratigraphic indicators such as graded bedding and crossbedding and the Burned Mountain metarhyolite is found in only one stratigraphic horizon throughout the study area. Some crossbedding in the feldspathic metasediments and vitreous quartzites has clearly been deformed (see Fig. 11), however, and care should be taken when using them to determine stratigraphic facing.

Several kinds of lineations are present in the Precambrian rocks. Biotite knots are stretched and oriented down the dip of the foliation in the lineated granodiorite, schist fragments in the arkosic conglomerate units and in the Moppin conglomerate are stretched and oriented down the dip of the foliation, and plagioclase megacrysts in the greenschists are commonly stretched and oriented in this same way.

FOLDING

Folding of the Precambrian units in the study area is common. Barker (1958) first delineated and named the Hopewell anticline and the Kiowa syncline, which trend northwest through the area. The axial trace of the

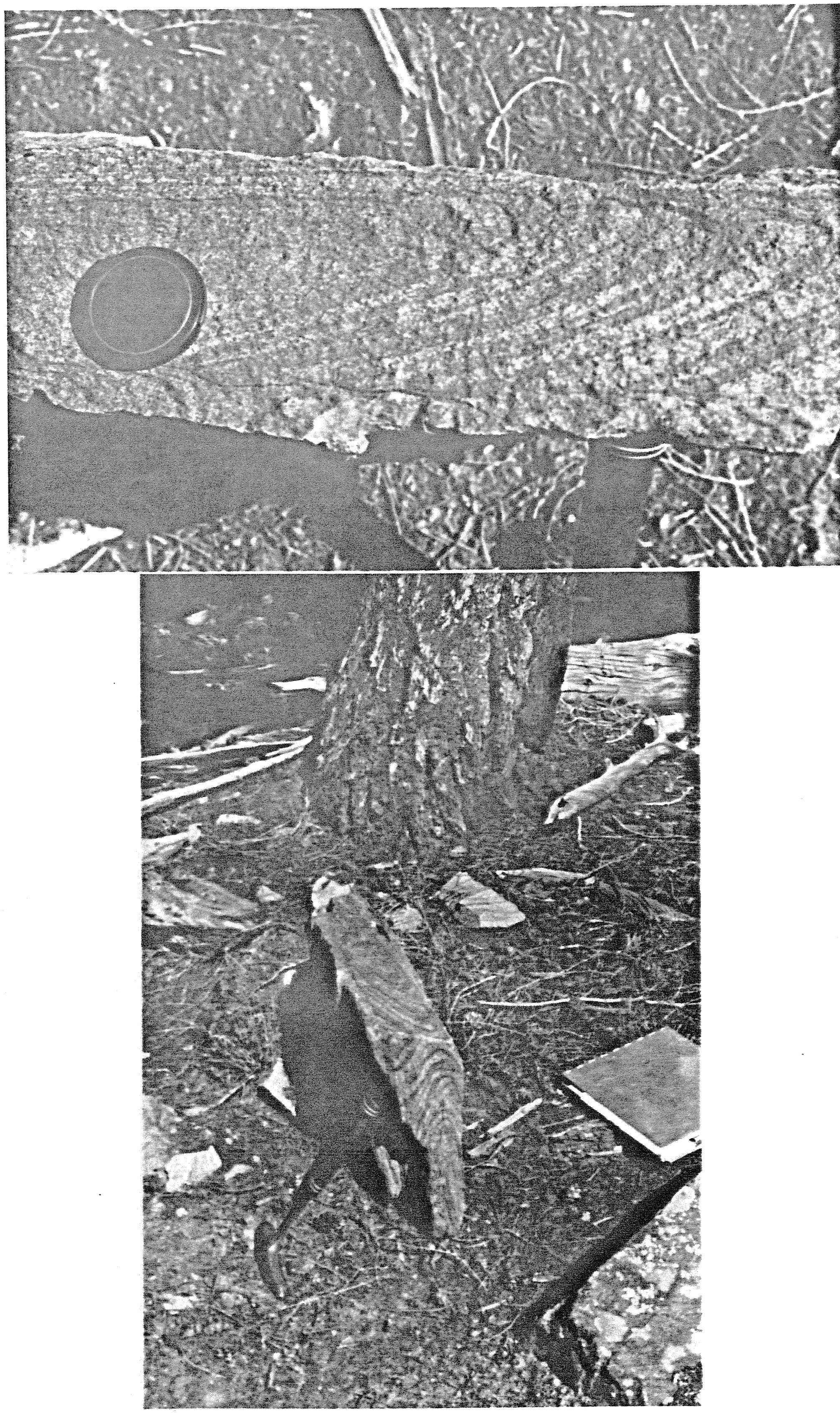
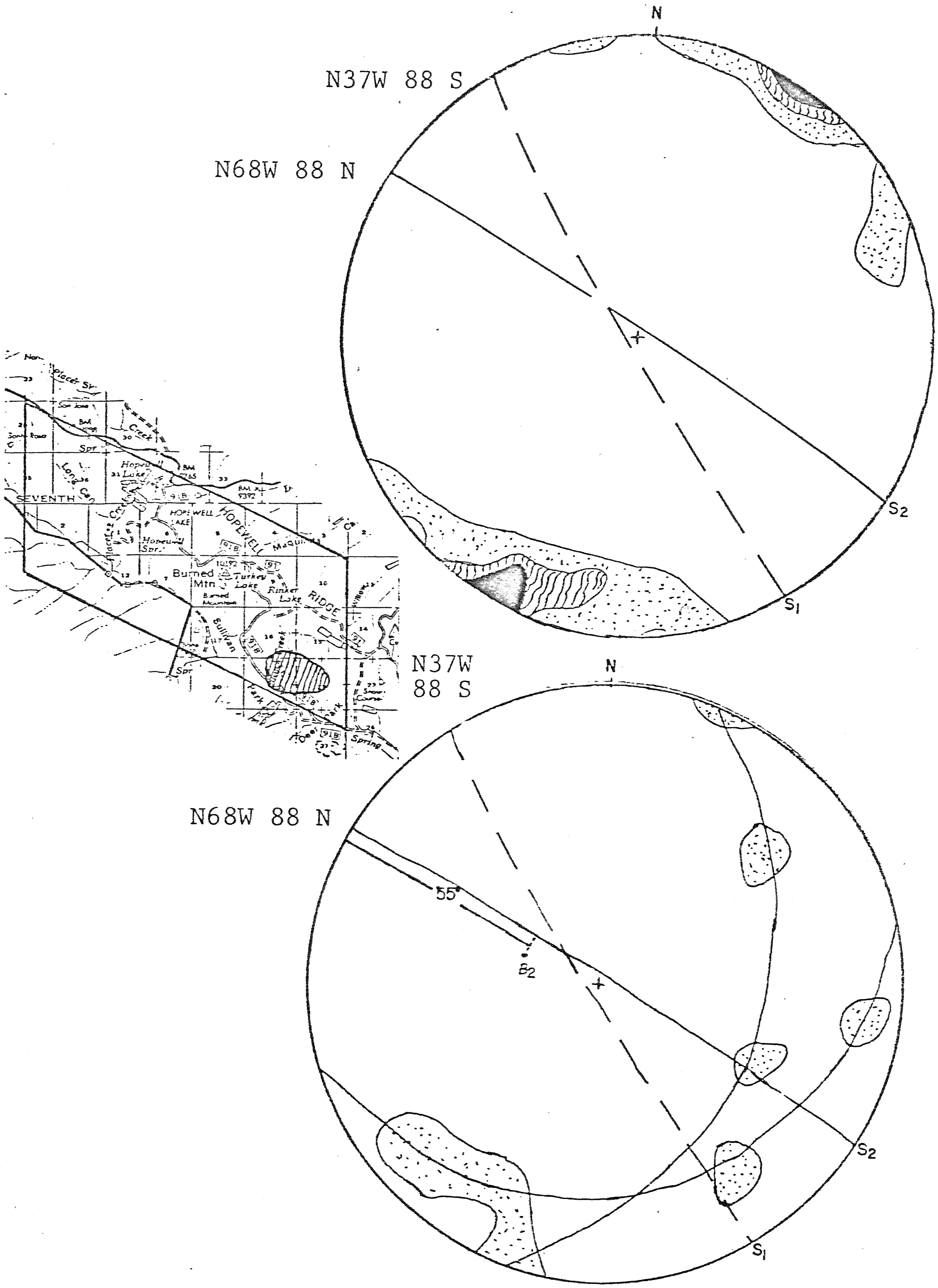


Figure 11

Deformed crossbedding in float block of metasubarkose. From south side of Burned Mountain, section 8, T.28N. R.7E.

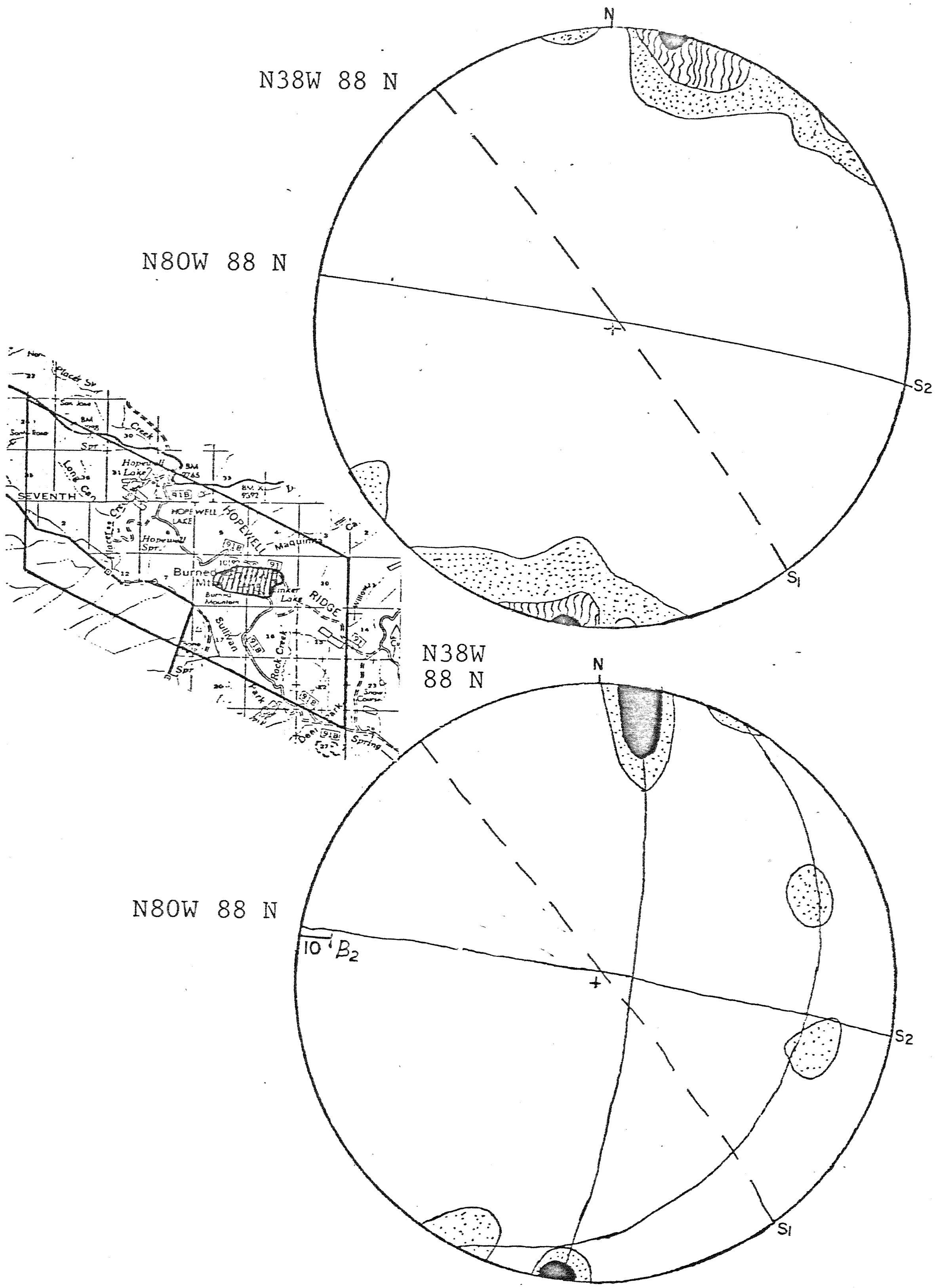
anticline has largely been obliterated in the study area by the lineated granodiorite and the granite of Hopewell Lake or is covered by Tertiary rocks. The trace of the axial-plane of the syncline could only be tentatively located because the only evidence of stratigraphic facing comes from crossbedding, much of which has been deformed, and limited outcrop of Precambrian rock in the area. Its supposed axial-trace is covered in the study area by Tertiary and Quaternary rocks so its location is at best only a guess. This structure appears to have been truncated to the southeast by the Vallecitos Valley fault.

A syncline was mapped along Rock Creek in sections 21 and 22, T.28N. R.7E. folding (F2) an anticline and syncline formed during an earlier deformation (F1) (see Fig. 12 and plate 1). Both folding episodes are defined on the basis of axial-plain foliation cutting across original bedding and changes of stratigraphic facing as indicated by graded bedding in the feldspathic metasediments. Structural data from this area is plotted on a stereo net (see Fig. 12). The first series of folds is near-isoclinal, trends N 37 W. The later fold trends N 68 W and plunge 45 degrees to the west. The fold axis of the second period of deformation is correct only if the first period of deformation resulted in the formation of planar surfaces which would be expected in


N
N37W 88 S
N68W 88 N
S2
S1
N37W
88 S
N
N68W 88 N
55°
B2
S2
S1
SEVENTH
HOPEWELL RIDGE
Burned
Mtn

very tight to isoclinal folds. The folds are truncated to the west by the Vallecitos Valley fault and to the east by the fault of Sheep Gulch. The second set of folds is tentatively thought to have been offset by the fault of Rinker Lake and to continue to the northwest in sections 8 and 9, T.28N. R.7E. before being again truncated by the Vallecitos Valley fault. The second set of folds has generaly the same trend as the Hopewell anticline and the Kiowa Syncline but have much smaller wavelengths (two to three hundred meters).

In the SW 1/2 of section 8 and 9 and the NW 1/4 of section 16, T.28N. R.7E. (see plate 1) there is fold of an earlier fold. The first fold is difficult to observe in the field and was delineated largely on the basis of stereo net projections (see Fig. 13). The first deformational episode produced a fold that is now trending N 38 W. The lineated granodiorite postdates this period of deformation as evidenced by the truncation of stratigraphy across the nose of the fold. The second period of deformation produced tight to isoclinal folds trending N 80 W and plunging 10 degrees to the west and probably is responsible for the weak to moderate foliation in the lineated granodiorite. The fold axis of the second period of deformation is correct only if the first period of deformation resulted in the formation of planar surfaces which would be expected in very tight to isoclinal folds.


N
N38W 88 N
N80W 88 N
S2
S1
N38W
88 N
N
N80W 88 N
10
B2
S2
S1
SEVENTH
HOPEWELL
RIDGE
Burned
Mtn
Hopewell Lake
Sullivan
Rock Creek
Spring

FOLIATION

All Precambrian rocks in the area of this study exhibit at least one axial-plane foliation and many exhibit a late-stage crenulation cleavage at a high angle to the dominant foliation. Portions of the Moppin series display two foliations that diverge from 5 to 35 degrees and may represent two folding events that were nearly coaxial. The foliations are the result of a prefered orientation of tabular or elongate crystals. The foliations strike N60W to E-W in the western portion of the area and N70W to N80E in the eastern half.

Figure 14 is a plot of 164 poles to foliation on a Schmit equal area net, and represents measurements taken from throughout the area of this study. This figure suggests the foliation is a result of near-isoclinal folding on a large scale with a near-vertical axial plane. This foliation is related to the large scale folds found in the area, the Hopewell anticline and Kiowa syncline of Barker (1958). These folds are interpreted as being formed by the second deformational episode resulting in the well developed and dominant foliation (S2). This foliation has largely obliterated the foliation (S1) formed by an earlier period of deformation. The best evidence of this earlier period of deformation (and foliation) is found in the pebble conglomerates of the feldspathic metasediments and the mafic

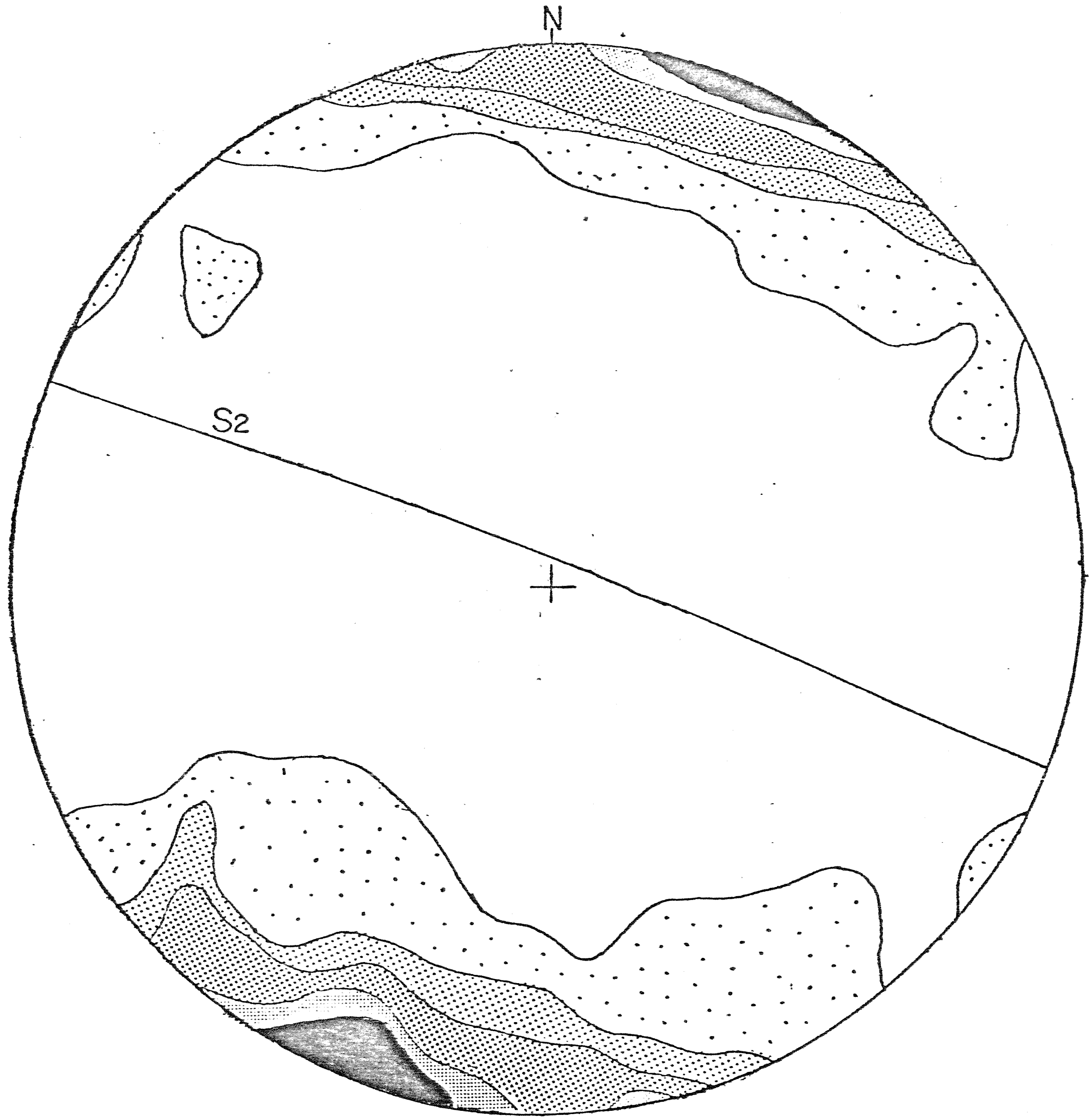


Figure 14

Equal area plot of poles to foliation from entire study area; 2-4-6-8-12 % contours per 1 % area, 14 % max (n-167).

schist of the Moppin series. No widespread petrofabric expression of a major third period of deformation was observed in the study area.

The best evidence for an earlier period of deformation comes from phyllitic pebbles in the subarkosic conglomerate units. They have one megascopic foliation (S1) while the conglomeratic matrix has two foliations, the dominant one (S2) being different than the one found in the phyllite fragments. Thin sections of the subarkosic conglomerates show the phyllite pebbles actually display both foliations (see Fig. 15). Close examination of some thin sections of Moppin series rocks seem to suggest that they may possess a weak second foliation, probably S2 where it only effected the rocks slightly after S1 had given them a well developed foliation.

A third deformation has resulted in a widely spaced (.5 to 1 cm) crenulation cleavage that is found in the Precambrian mafic rocks, felsic volcanic and microcline-muscovite-quartz schist (see Fig. 16). It trends generally N 20 W to N 20 E and dips at 50 to 90 degrees to both the east and west. This crenulation cleavage is found throughout the study area.

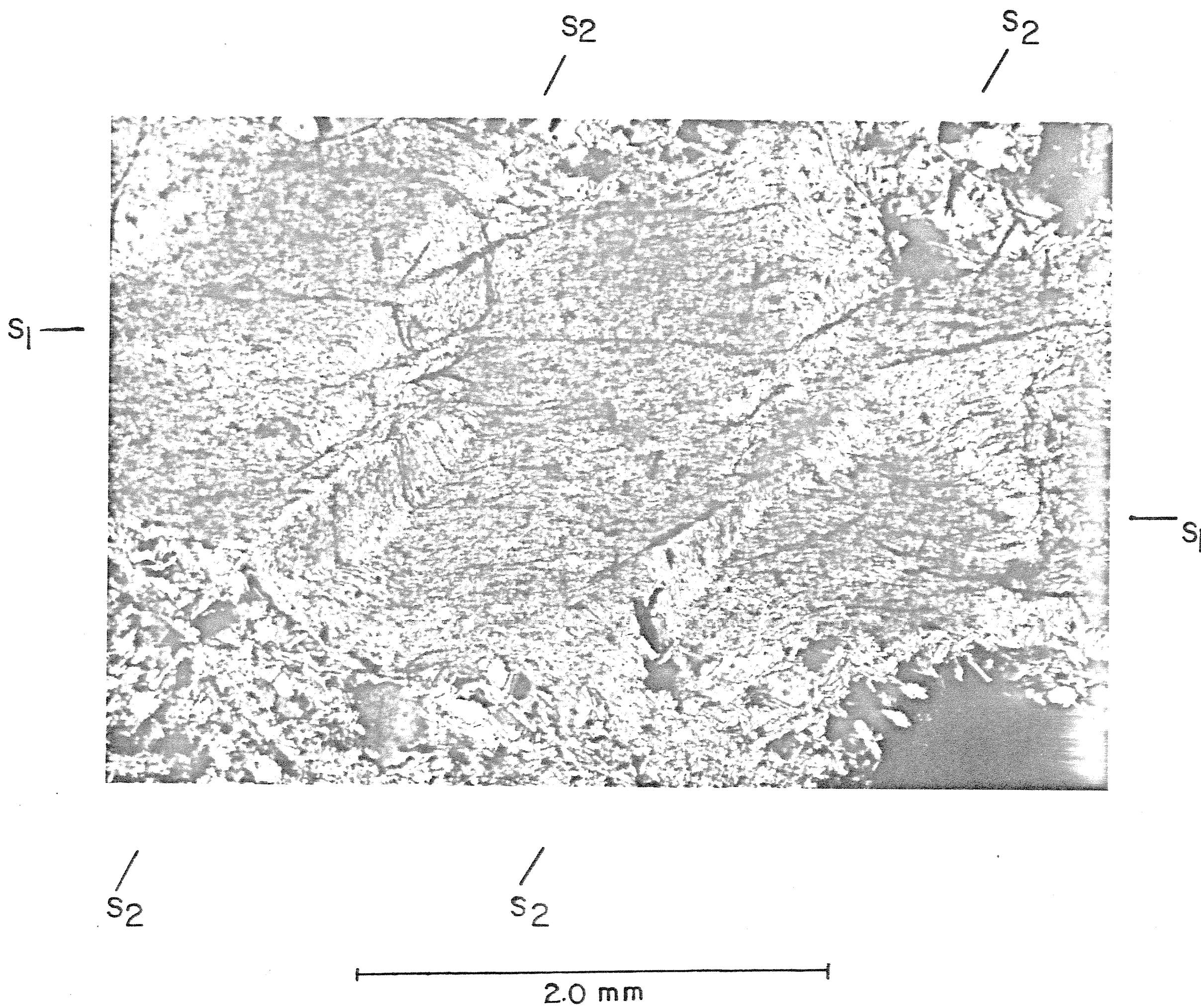


Figure 15

Photomicrograph of phyllite fragment in subarkosic metaconglomerate showing two foliations (25X and crossed Nicols).

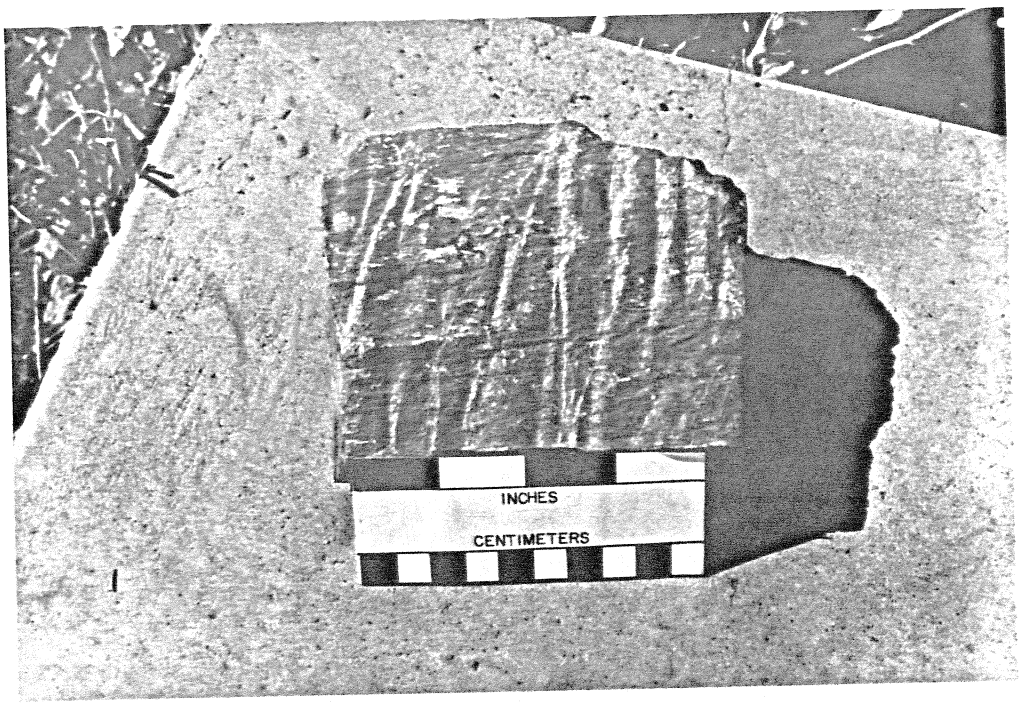


Figure 16

Photograph of Moppin greenschist with late stage slip cleavage. From along Rock Creek, section 15, T.28N. R.7E.

LINEATIONS

Various lineations were measured in the field and most were found to be oriented normal to the strike of the foliation and within the plane of the foliation. Stretched biotite knots in the lineated granodiorite are common as are altered megacrysts in the greenschists of the Moppin series. In the Moppin conglomeratic unit and the metasubarkosic conglomeratic unit the long axis of phyllite fragments define a strong lineation (see Fig. 17). Furthermore, the fragments have their long axis oriented at various angles to bedding planes. If the deformational history of the area were simple (one deformational episode), this would suggest that they are "a" lineations (Hobbs and others, 1976). However, at least two deformational episodes have been observed in this area so no directional movement should be assigned to a lineation, unless the age of that lineation can be clearly established.

Figure 18 is an equal area plot of 17 lineations from throughout the study area. The lineations form a maxima that coincides with a line formed by the the intersection of the axial-plain foliations (S1 and S2).

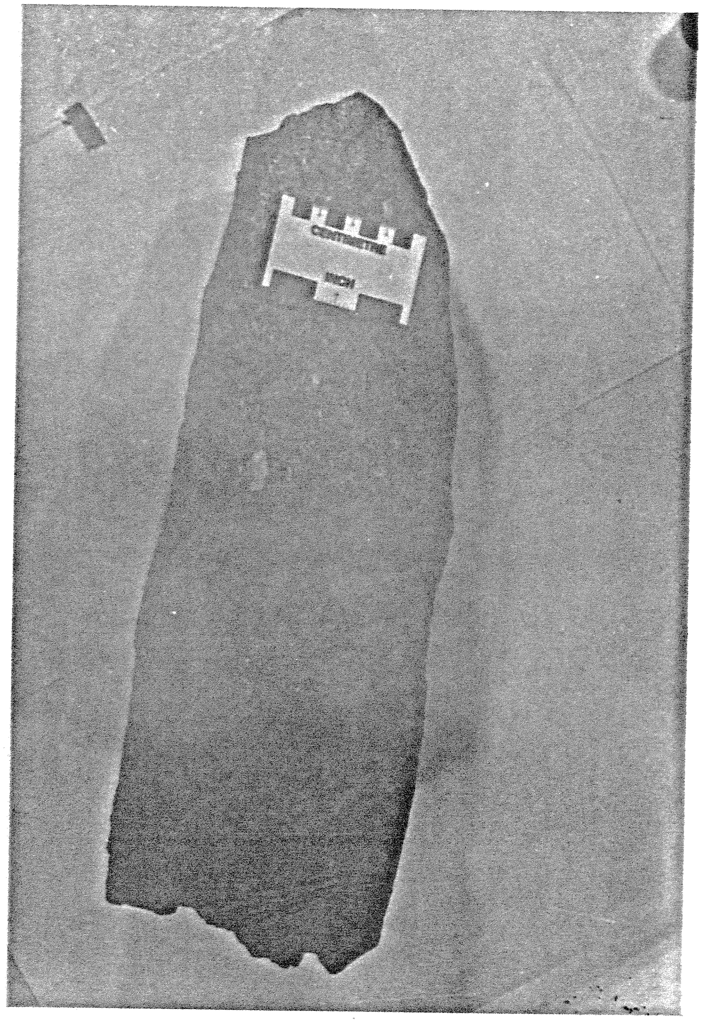


Figure 17

Photograph of subarkosic metaconglomerate with stretched schist fragments forming a lineation. Finer-grained metasubarkose displays well-developed crossbedding and graded bedding. The main foliation in this sample is normal to sedimentary layering. From east side of Burned Mountain, section 9, T.28N. R.7E.

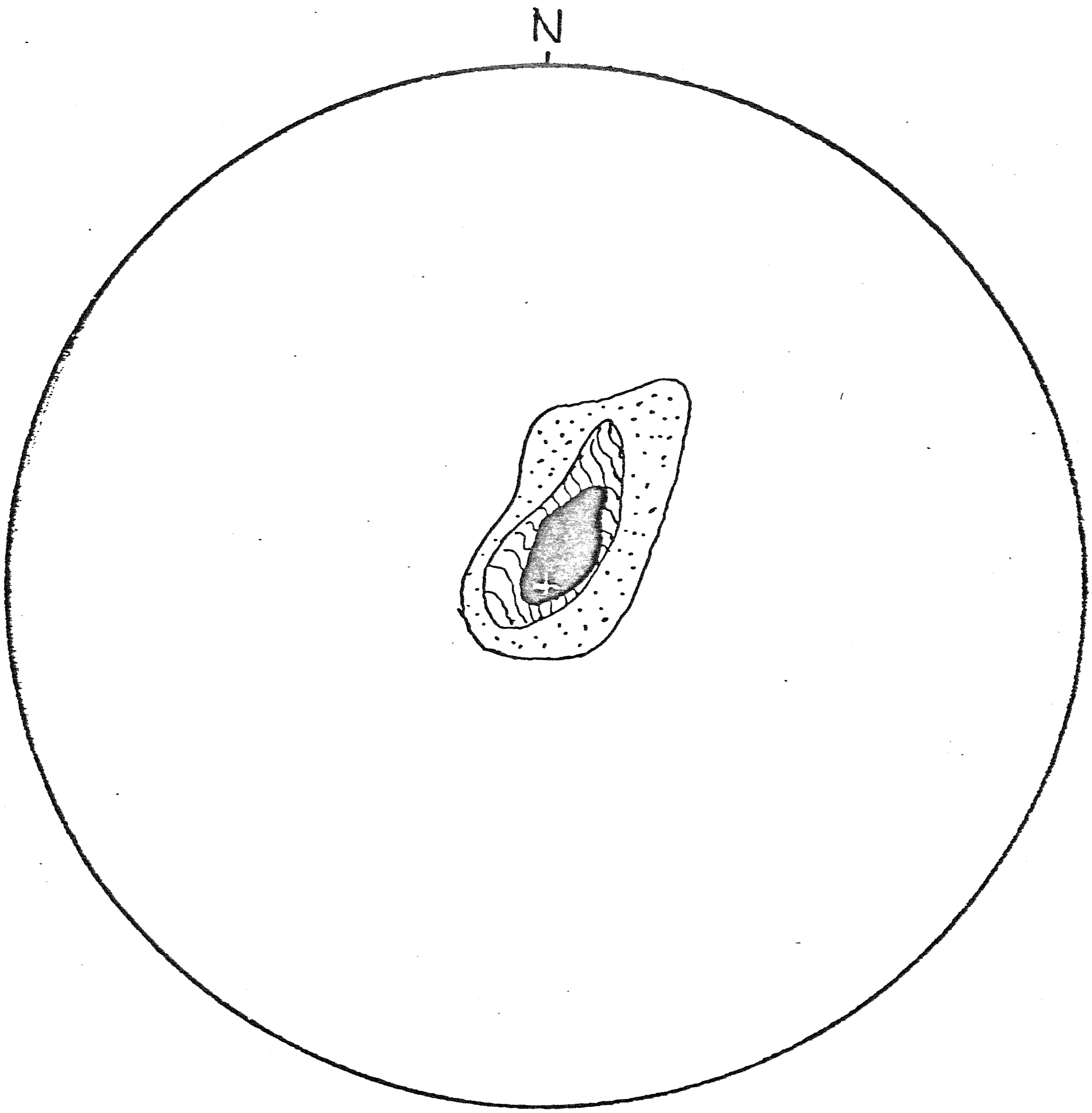


Figure 18

Equal area plot of linetions from entire study area; contours 5-15-35% per 1% area, 51% max (N 17). Maxima falls near the intersection of two foliations.

FAULTS

There are three major faults in the area of this study. All offset Precambrian and Tertiary rocks, but are largely covered by Quaternary alluvium and colluvium.

The Vallecitos Valley fault (named by Barker, 1958) is the largest in the area both in terms of strike length and apparent displacement and trends N 45 W (see Plate 1). It crosses the entire area with little or no change in strike, suggesting it is near-vertical. Vitreous quartzite and Tertiary rocks are found south of the fault. These same Tertiary rocks make up the upper part of the Tertiary section north of the fault and the quartzites are probably the uppermost Precambrian rocks in the area. This suggests that the most recent movement along the Vallecitos Valley fault was down to the south. The fault zone itself is almost never exposed although weak shear zones in Eureka Canyon and Long Canyon are probably related. The fault line scarp is very obvious if observed from a distance (see Fig. 19), and the Vallecitos Valley fault has controlled the location of several valleys (Long Valley, the Vallecitos Valley, and Sullivan Park; see plate 1).

The amount of throw on this fault (south side down) has been estimated to be between 300 (Hutchinson, 1968) and 600 feet (Barker, 1958). Barker cites no evidence for his figure, while Hutchinsons' figure is based on correlation of

Figure 19

Aerial photograph of Vallecitos Vally Fault, looking northwest from Sullivan Park.

the elevation of a basalt flow south of the fault with the elevation of debris of basalt north of the fault. There is no way to determine the amount of throw on this fault in the area of this study.

The fault of Rinker Lake is defined on the bases of stratigraphic data alone and is located in sections 9, 16, and 17 T.28N. R.7E. It offsets Precambrian stratigraphy in a right lateral sense along a strike of approximately N 45 E. The Tertiary rocks suggest a vertical displacement, NW being down. This would suggest either two periods of movement along this fault or oblique movement. The offset of Precambrian rocks may be alternatively due to complex folding in the area, but poor outcrop in the area make distinction impossible. Prospect pits line up along a possible northern extension of the fault (suggesting a linear feature in the area). The fault is truncated to the south by the Vallecitos fault and dies out in the lineated granodiorite to the north.

A near-vertical fault (here called the fault of Sheep Gulch) trends approximately N 45 E and offsets Precambrian rocks in a right lateral sense in sections 15 and 22 T.28N. R.7E. This fault was also defined on the bases of stratigraphic data alone, although it is largely covered by Quaternary glacial till.

DISCUSSION

It is clear that the structure of the area is much more complex than originally thought (Barker, 1958; and Hutchinson, 1968) and this summary is by no means the final word on the structure of the northern Tusas Mountains. For a more complete understanding of the structural history, detailed work in a number of smaller areas, with good outcrop should be undertaken. One such area in the present study area would be the Rock Creek drainage. The following structural events appear to have effected the and/or occurred in the present study area:

1) Minor uplift and erosion of the Moppin series which continued through Burned Mountain metarhyolite time. The Moppin series rocks in adjacent areas (Brazos Box, Jawbone Mountain, and Tusas Mountain) contain either pillows or iron formation which suggests the rocks were deposited underwater. Sufficient uplift occurred to produce the fluvial subarkosic metaconglomerate unit which contains Moppin series schist fragments and cobbles of metarhyolite. If flattened and stretched pumice is indicative of welded ash flow tuffs, then the environment may have even been subareal, or at least shallow water.
2) Precambrian rocks in the area were subjected to deformation, producing folds and a foliation which has been largely obliterated by later deformation. This

foliation is now only well-preserved in phyllite pebbles in the feldspathic metasediments and rarely in mafic schists of the Moppin series.

3) A second period of deformation produced northwest trending, near-isoclinal or tight folds (Hopewell anticline and Kiowa syncline) and the well-developed axial-plane foliation now found in the rocks. The folds plunge to the northwest at 10 to 55 degrees.
4) A crenulation cleavage, trending N 20 W to N 20 E, deformed the Precambrian rocks.
5) Uplift occurred during the early Phanerozoic. Phanerozoic rocks to the west of the study area thin onto or pinch out entirely against the Brazos uplift.
6) Faulting of the Precambrian and Tertiary rocks during or following the late Tertiary. Faulting may have occurred before this time but latest movement cuts Tertiary rocks in and around the study area.

Grambling (1981) suggests that the Ortega quartzite which stratigraphically overlies the northern portions of the Pecos greenstone belt has undergone two periods of nearly coaxial deformation. His first deformation produced isoclinal folds and his second tight to isoclinal folds, both fold axes trend roughly east-northeast. The nearly coaxial deformation documented in this study area may be similar. Bingler (1965) suggests three periods of deformation to the southeast of the area in the La Madera quadrangle. His first two periods of deformation (folds trending NW-SE (S1) and E-W (S2)) match quite well with the deformational episodes suggested here.

The presence of these multiple periods of deformation requires that much care be taken before attempting to define, let alone correlate stratigraphy over large distances or even over the distances found in this study.

METAMORPHISM

Precambrian rocks in the Tusas Mountains have undergone at least one period of regional dynamothermal metamorphism. In the study area all Precambrian rocks, both supracrustal and plutonic, contain assemblages of the low temperature range of low grade metamorphism (Winkler, 1979) or lower greenschist facies (Miyashiro, 1973).

The Burned Mountain metarhyolite and feldspathic metasediments do not contain mineral assemblages which clearly reflect changing metamorphic conditions. The best mineralogic evidence of metamorphic grade comes from the mafic metavolcanic and metavolcaniclastic rocks of the Moppin series which contain the following mineral assemblages:

Chlorite + Muscovite + Albite/Oligoclase + Quartz + Calcite

Chlorite + Albite/Oligoclase + Muscovite + Epidote/Clinozoisite + Quartz

Chlorite + Quartz + Muscovite

Chlorite + Actinolite + Albite/Oligoclase + Quartz + Calcite

Chlorite + Calcite + Quartz + Muscovite + Epidote/ Clinozoisite + Albite/Oligoclase

Tremolite was not distinguished from actinolite, but due to the associated minerals actinolite would be expected. The mineral assemblage associated with the lower temperature range of low grade metamorphism or the greenschist facies is (Winkler, 1979; Miyashiro, 1973):

actinolite + chlorite + epidote/clinozoisite + albite/ oligoclase + quartz +/- carbonate +/- muscovite

The presence of actinolite and/or chlorite instead of hornblende, plagioclase in the albite/oligoclase range, and lack of garnet suggests that the rocks never reached the upper temperature range of low-grade metamorphism. The presence of epidote/clinozoisite and lack of lawsonite suggests these rocks are beyond very low-grade metamorphism. The described mineralogy is consistent with the mafic rocks of the Moppin series being metamorphosed to the lower temperature range of low-grade metamorphism (Winkler, 1974). The mineralogy described for rocks in the Moppin series is also consistent with the mineralogy found in the greenschist facies of the medium-pressure type as described by Miyashiro (1973).

The temperatures associated with the observed mineral assemblage are between 350 and 500 degrees celsius according to Miyashiro (1973), Winkler (1974), and Holdaway, (1978). The pressure range over which this assemblage occurs is quite wide, but was probably never above 8 to 10 Kbar, but could have been appreciably lower.

Additional periods of dynamothermal metamorphism may have effected some of the Precambrian rocks in the area. Three later thermal events have been documented at approximately 1490m.y. (Rb/Sr by Maxon, 1976), 1425m.y. (Rb/Sr Long, 1976), and 1350m.y. (K/Ar Barker and Friedman, 1974) to the south of the study area. Inclusions in megacrysts throughout the area, at various angles to the foliation in the rock are probably due to the break down of Plagioclase to albite and epidote during later thermal events.

Contact metamorphic and/or metasomatic effects adjacent to the "granitic" intrusives are not apparent. There are no contact metamorphic minerals or remnants thereof near the contact, nor is there a hornfels developed. This would suggest either intrusion took place when the country rock was at or near the temperatures of the intrusive (unlikely that intrusives were as cool as 500 degrees as metamorphism suggests) or that the effects of contact metamorphism were removed by later thermal events. Rocks of the Moppin series however have been altered by the addition of some K2O (see geochemistry section).

No evidence was found in the study area for retrograde metamorphism although retrograde effects have been noted to the east (Kent, 1980; Bingler, 1968; Barker, 1958). Samples containing what may be pseudomorphs of chlorite/ actinolite after hornblende porphyroblasts, were found as float along the eastern boundry of the study area.

Metamorphic grade increases to lower amphibolite facies to the east, south and north of the study area, where amphibolites are common, and staurolite and garnet are found in the rocks (Kent, 1980; Bingler, 1968; Muehlberger, 1968; and Barker, 1958).

GEOCHEMISTRY

Ten rocks samples from the study area were analysed for major element chemistry by atomic absorption methods (see appendix II). The analyses are presented along with CIPW norms in Tables 2 (felsic volcanics and intrusives) and 3 (mafic Moppin series rocks). Each table also contains rock analyses from other Precambrian studies in the general area and a number of average rock compositions (after Nockolds, 1954). Table 4 presents unpublished analyses (Robertson, personal communication) of rocks from in and adjacent to the study area and average compositions of Archean tholeiites (after Condie, 1976).

SUPRACRUSTAL ROCKS

An attempt to chemically characterize Moppin series mafic rocks from the study area using Irvine and Baragar's (1971) classification scheme yielded contradictory results. The rocks plotted as both alkaline and subalkaline on a K2O + Na2O versus SiO2 diagram (Fig. 20). An An-Ab-Or diagram (Fig. 21) shows that some of these mafic rocks are potassium-rich and others potassium-poor. The analyses fall in the calc-alkaline field on a Al2O3 versus normative plagioclase diagram (Fig. 22), but appear to be both calc-alkaline and tholeiitic on a AFM diagram (Fig. 23). They are basalts and andesites on a normative color index versus normative plagioclase diagram (Fig. 24), but range from basalt to rhyolite when plotted on a Jensen cation diagram (Fig. 25, Jensen, 1976). The Jensen diagram also shows these "mafic" rocks to be both calc-alkaline and tholeiitic.

A second attempt to characterize the Moppin series mafic rocks met with more consistent results. The analyses were plotted on a series of diagrams proposed by Miyashiro (1974) and Miyashiro and Shido (1975) for non-alkaline (subalkaline) rocks. Figure 26 is a FeO(T) versus FeO(T)/MgO (FeO(T) is total iron as FeO) on which the analyses plotted in the tholeiitic field except for samples which show obvious petrographic evidence (large secondary quartz eyes) of being effected by nearby "granitic" intrusives (samples TG-08, B8a1, and Hp-1 on diagrams). Figure 27 is a SiO2 versus FeO(T)/MgO diagram, on which the analyses plot in the tholeiitic field except for two of the three samples effected by the intrusives. On a TiO2 versus FeO(T)/MgO diagram (Fig. 28) except for the three samples from near the intrusives the analyses plotted in tholeiitic fields.

Samples of mafic rocks from this study area are enriched in K2O and Na2O and depleted in total Fe, MgO, and CaO when compared to both Nockolds (1954) modern average tholeiitic basalt and gabbro and Condie's (1976) average Archean tholeiite chemical compositions (see Tables 3 and 4).

The felsic volcanic (Burned Mountain metarhyolite) analyses were plotted on Irvine and Baragar's normative color index versus normative plagioclase diagram (Fig. 24), as well as on the Jensen cation diagram (Fig. 25). On each diagram the metarhyolite plotted in the rhyolite field.

INTRUSIVE ROCKS

Analyses of intrusive rocks from the study area are plotted on an An-Ab-Or ternary diagram (Fig. 29, after Barker, 1979) for classification purposes. Two samples of the lineated granodiorite (Maquinita granodiorite) plotted as a trondhjemite (TG-07) and on the tonalite-granodiorite boundary (TG-10). The granodiorite of Spring Creek (B8a2) plotted on this boundary also. The granite of Hopewell Lake (Tusas Granite TG-09) plotted as a trondhjemite. For comparison, the intrusive rock analyses from this study were plotted, along with analyses of intrusive rocks from various other studies in the northern Tusas Mountains on Barkers' An-Ab-Or diagram (Fig. 30). On these diagrams (Figs. 29 and 30) trondhjemite may contain up to 30 percent normative Or. In petrographic classification of the rocks from the study area estimated modal mineral contents were used and the classification system recommended by the IUGS (Streckeisen, 1973). The alkali feldspar most common in the intrusive rocks was orthoclase with microcline usually present but minor. Because orthoclase contains Na, the petrographic identification may not agree with the geochemical classification.

DISCUSSION

Because some of the mafic rocks seem to be enriched in K_2O, their plots on a K_2O + Na_2O versus SiO_2 diagram (Fig. 20) would be in the alkaline instead of the subalkaline field Chemical analyses from other Precambrian terranes in northern New Mexico and southern Colorado suggest, mostly subalkaline volcanic rocks are present. Alkaline rocks have for the most part, not been documented. If the rocks are indeed subalkaline then Irvine and Baragar's classification scheme will work.

Use of whole-rock chemistry for classification of Precambrian metavolcanic rocks is not without its difficulties, especially if the compositions of modern unaltered volcanic rocks form a fundamental part of such a classification. Comparisons between Precambrian and modern basalts is not entirely satisfactory, due to various types of alteration that typically affect Precambrian basalts subsequent to their eruption. Hart and others (1969) suggest K_2O content increases in tholeiitic basalts as the result of alteration both during low grade metamorphism and exchange with seawater. In 1974, Hart demonstrated that Al_2O_3 , CaO, and SiO_2 are lost and MnO and K_2O increase as the result of sea floor alteration and that MgO and Na_2O undergo significant but inconsistent changes. MacGeehan and

MacLean (1980) suggest basalts may show enrichment of Si and Na and depletion of Fe, Mg, Ti, Mn, and Ca distal to a suggested brine discharge locality and ore deposit reportedly formed in response to a hydrothermal cell in the Abitibi greenstone belt. Condie and others (1977) suggest that Na, Mg,and K are depleted and Ca is enriched during metamorphism (epidotization and carbonitization-chloritization) of tholeiitic flows in the Barberton greenstone belt.

The Moppin series mafic rocks in the present study area have undergone low grade metamorphism and are in places mineralized. Presence of pillows in adjacent areas suggests that portions of the Moppin series may have accumulated subaqueously, and therefore have undergone sea floor alteration. In addition, there is evidence from the mafic rocks adjacent to the lineated granodiorite and the granite of Hopewell Lake that contact metasomatism may have effected them. Barker (1958) reports addition of large amounts of potassium to the rocks south of this study area and the K_2O enrichment present in the Burned Mountain area may be a fringe effect of that enrichment.

For all of these reasons the use of whole-rock geochemical analyses to characterize, name, and classify the metavolcanic rocks found in the Tusas Mountains, at least in the present study area is apparently not productive.

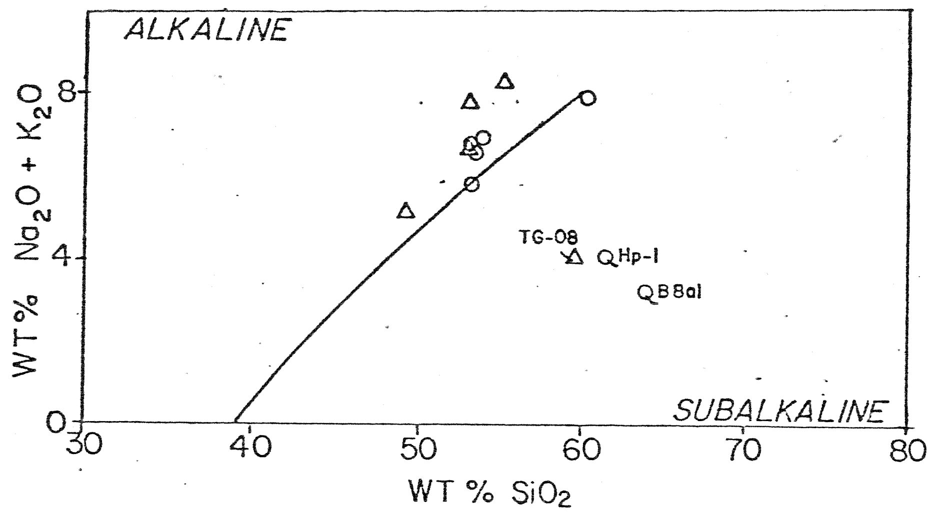
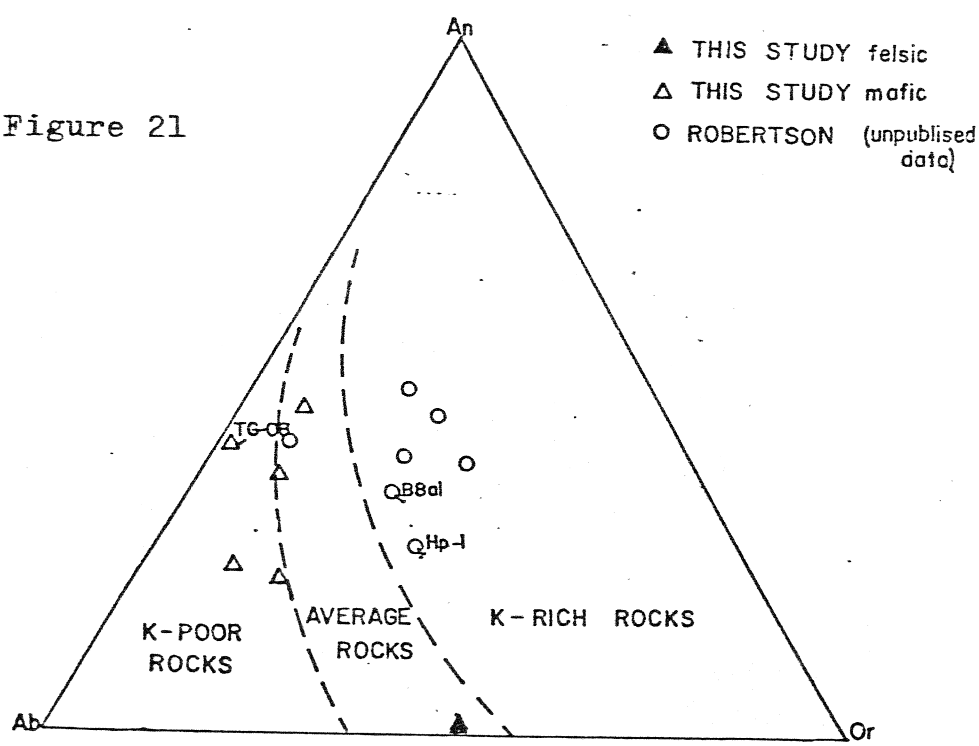


Figure 20

K2 Na2O vs. SiO2 diagram after Irvine and Baragar (1971).

Figure 21



An-Ab-Or diagram after Irvine and Baragar (1971).

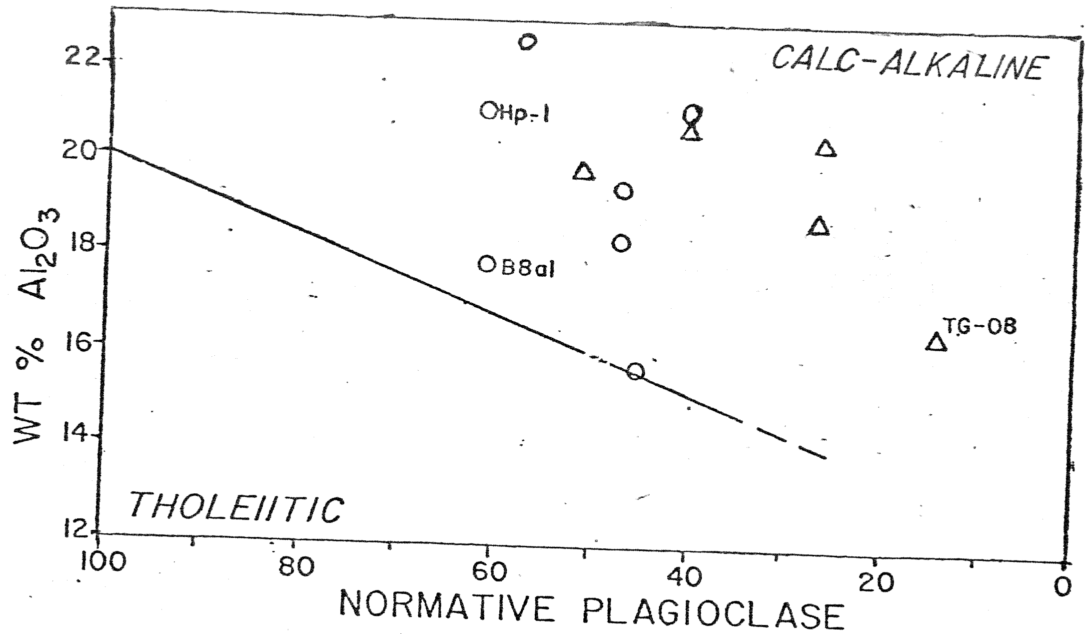
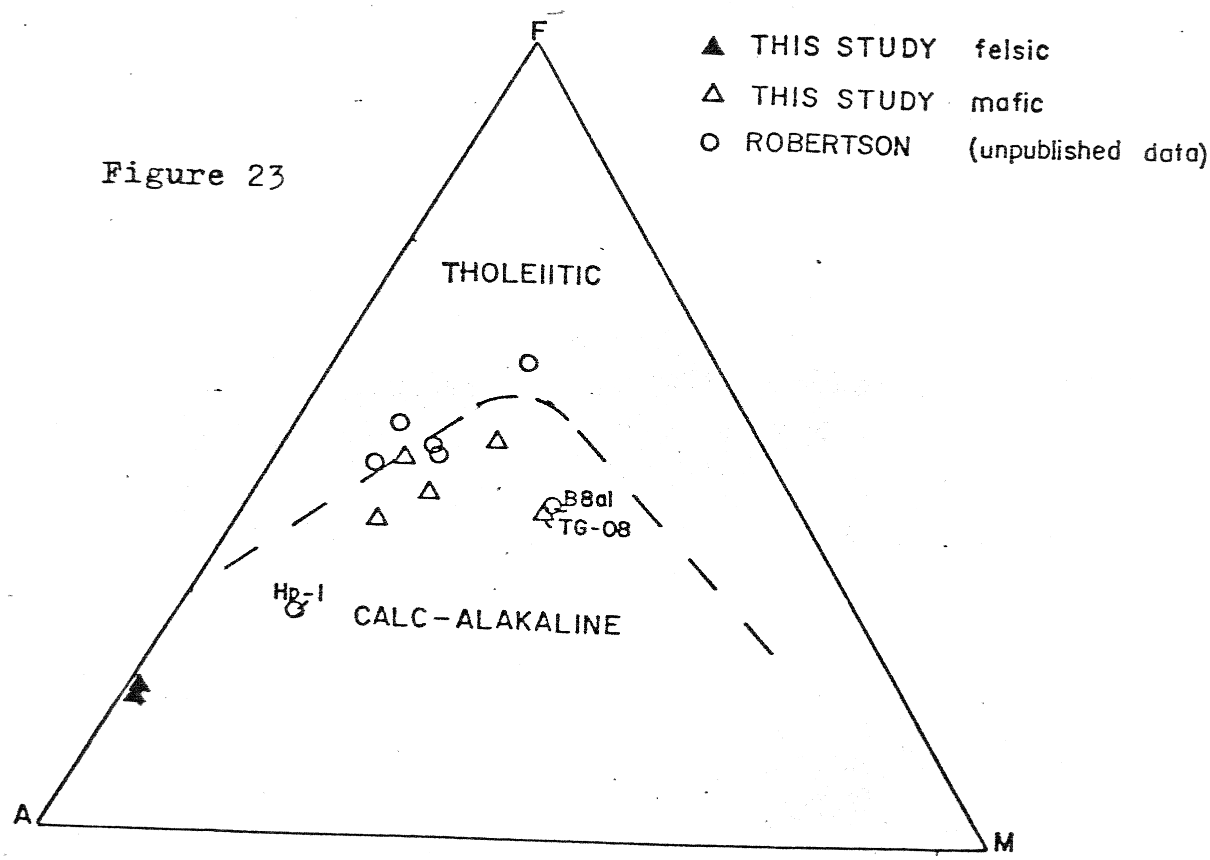


Figure 22

Al203 vs. Normative Plagioclase after Irvine and Baragar (1979).

Figure 23



AFM diagram after Irvine and Baragar (1971).

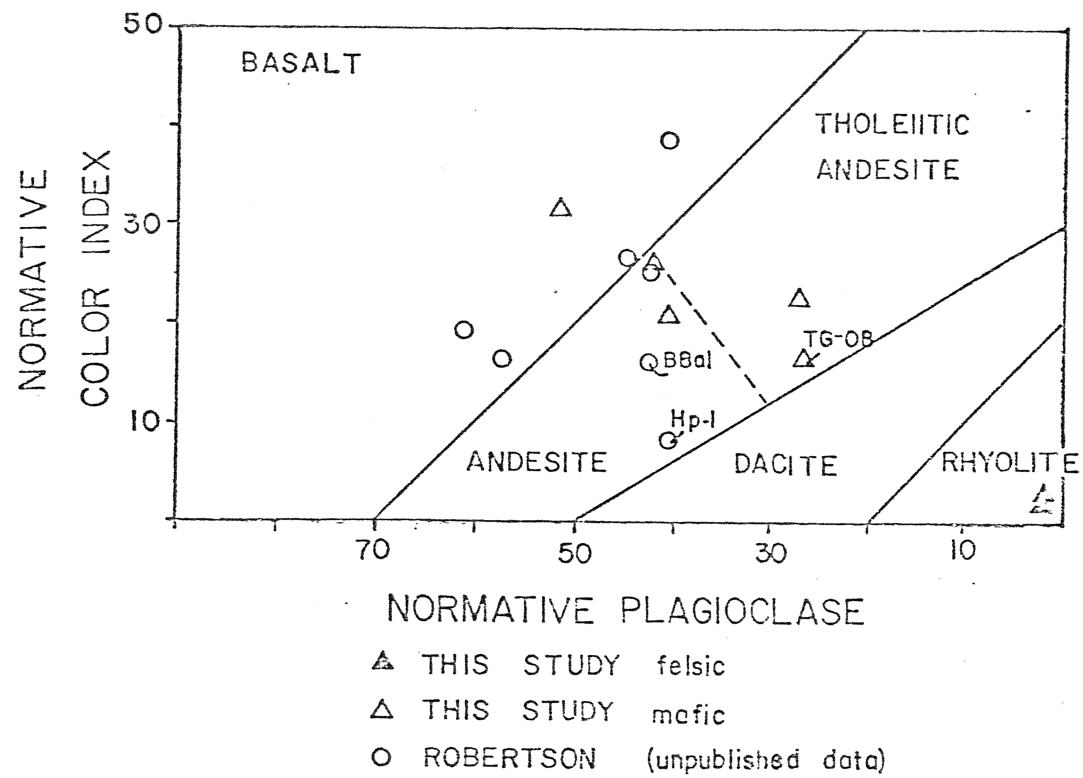
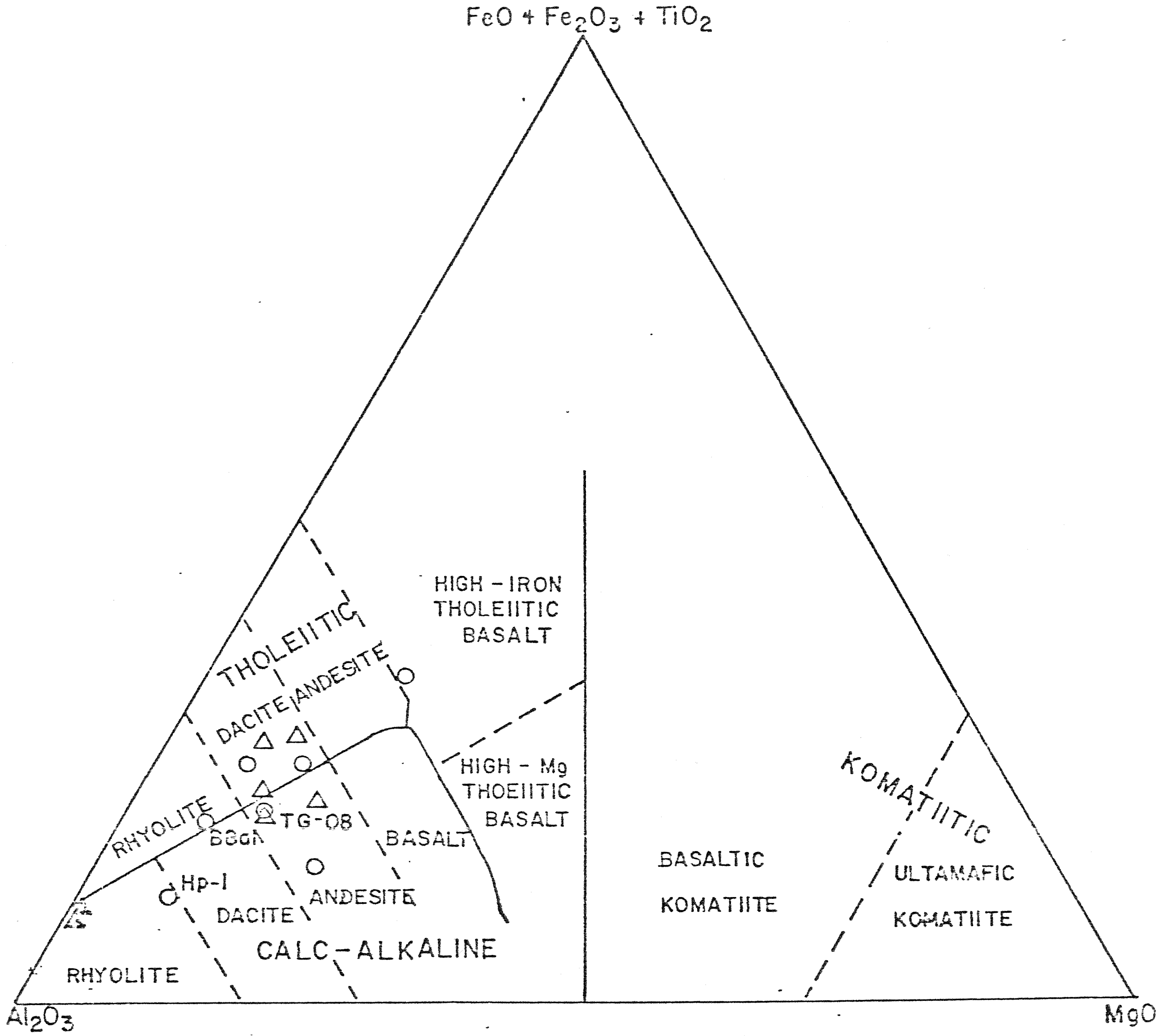


Figure 24

Normative Color vs. Normative Plagioclase diagram after Irvine and Baragar (1971).



△ THIS STUDY felsic

○ ROBERTSON (unpublished data)

△ THIS STUDY mafic

Figure 25

Jensen Cation diagram (after Jensen, 1976).

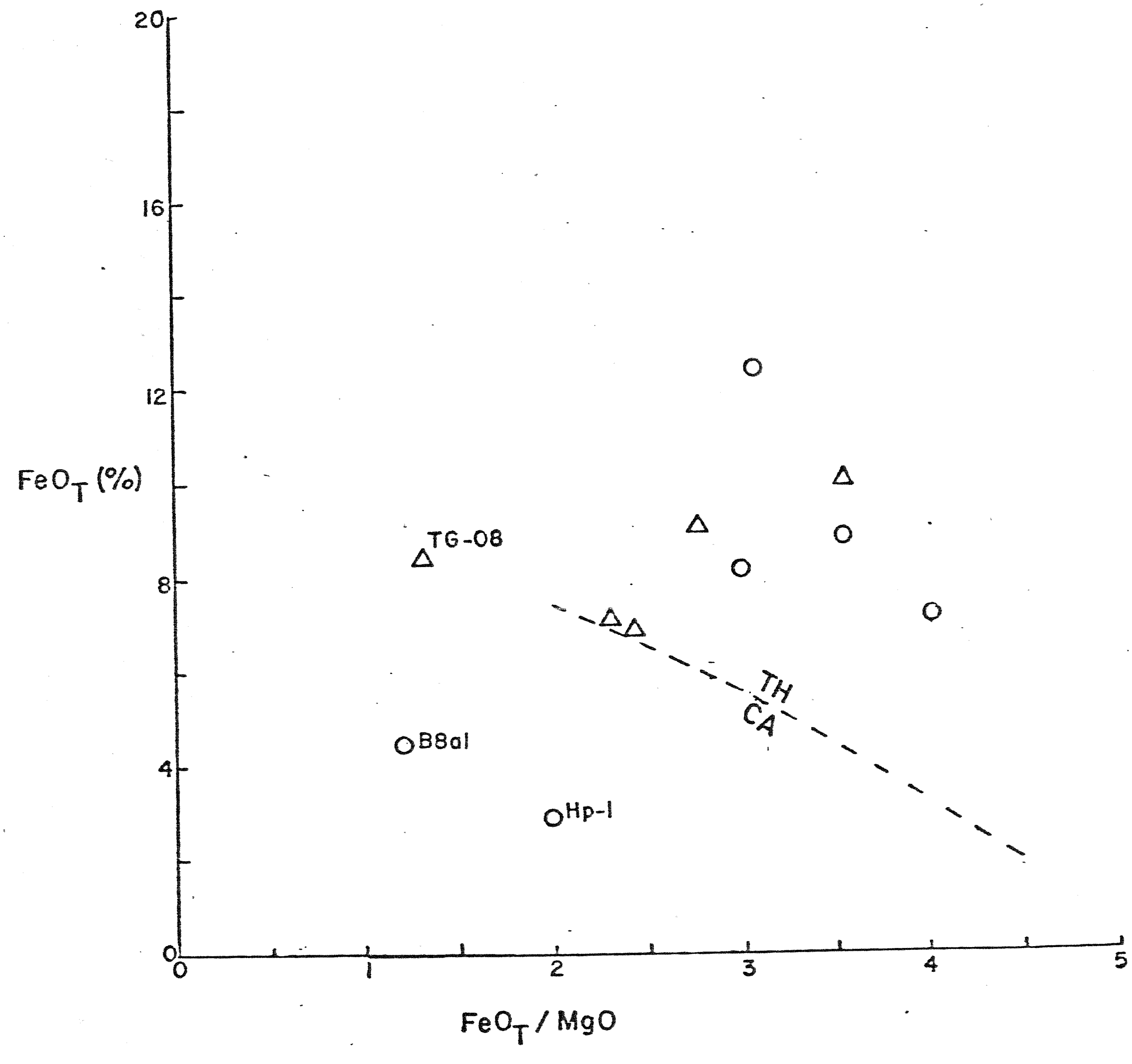


Figure 26

FeO(T) vs. FeO(T)/MgO diagram after Miyashiro (1974). CA Calc-Alkaline; TH Tholeiitic (FeO(T) is total iron as FeO).

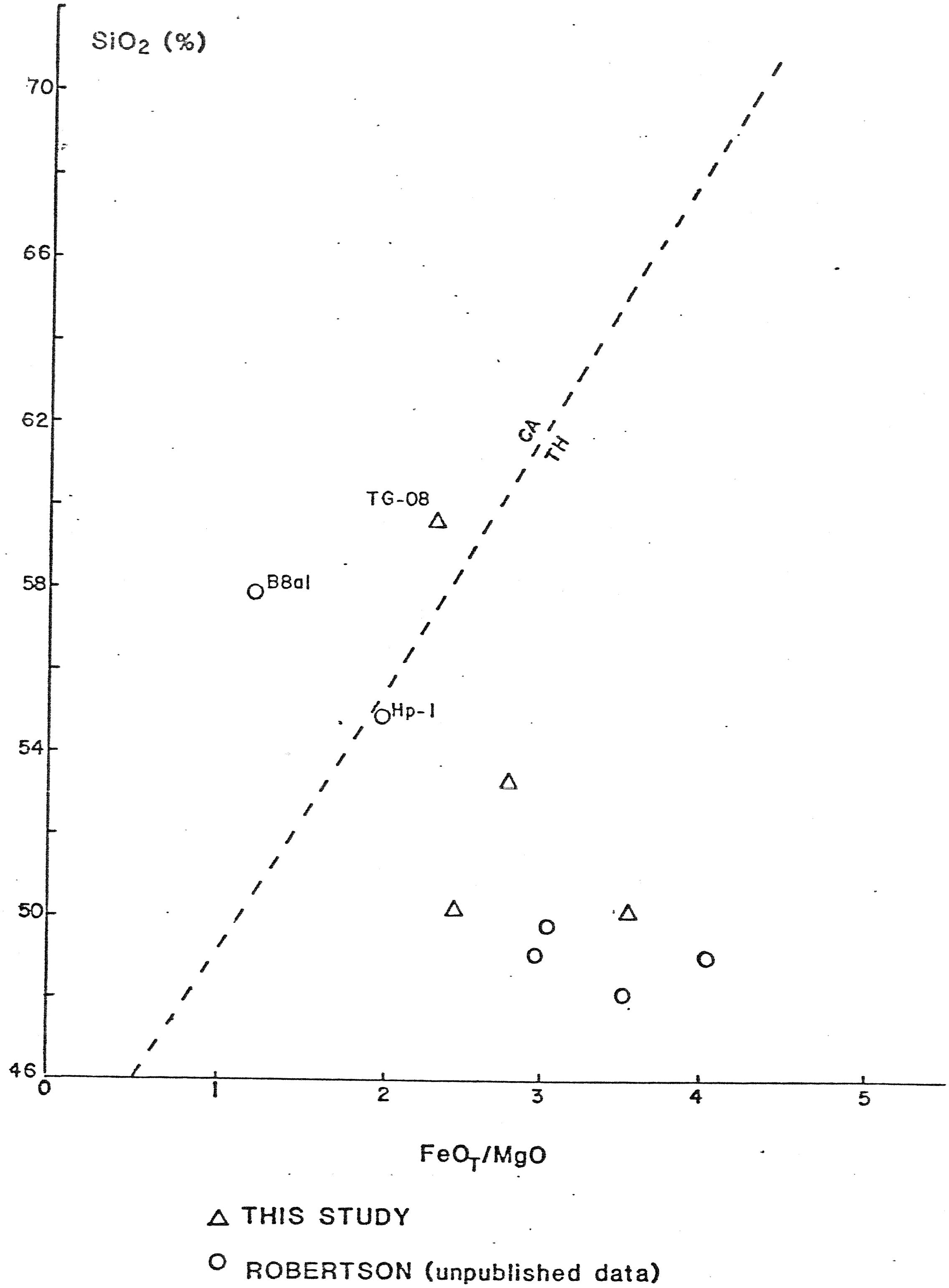


Figure 27

SiO2 vs. FeO(T)/MgQ diagram after Miyashiro and Shido (1975). CA Calc-Alkaline; TH Tholeiitic (FeO(T) is total iron as FeO).

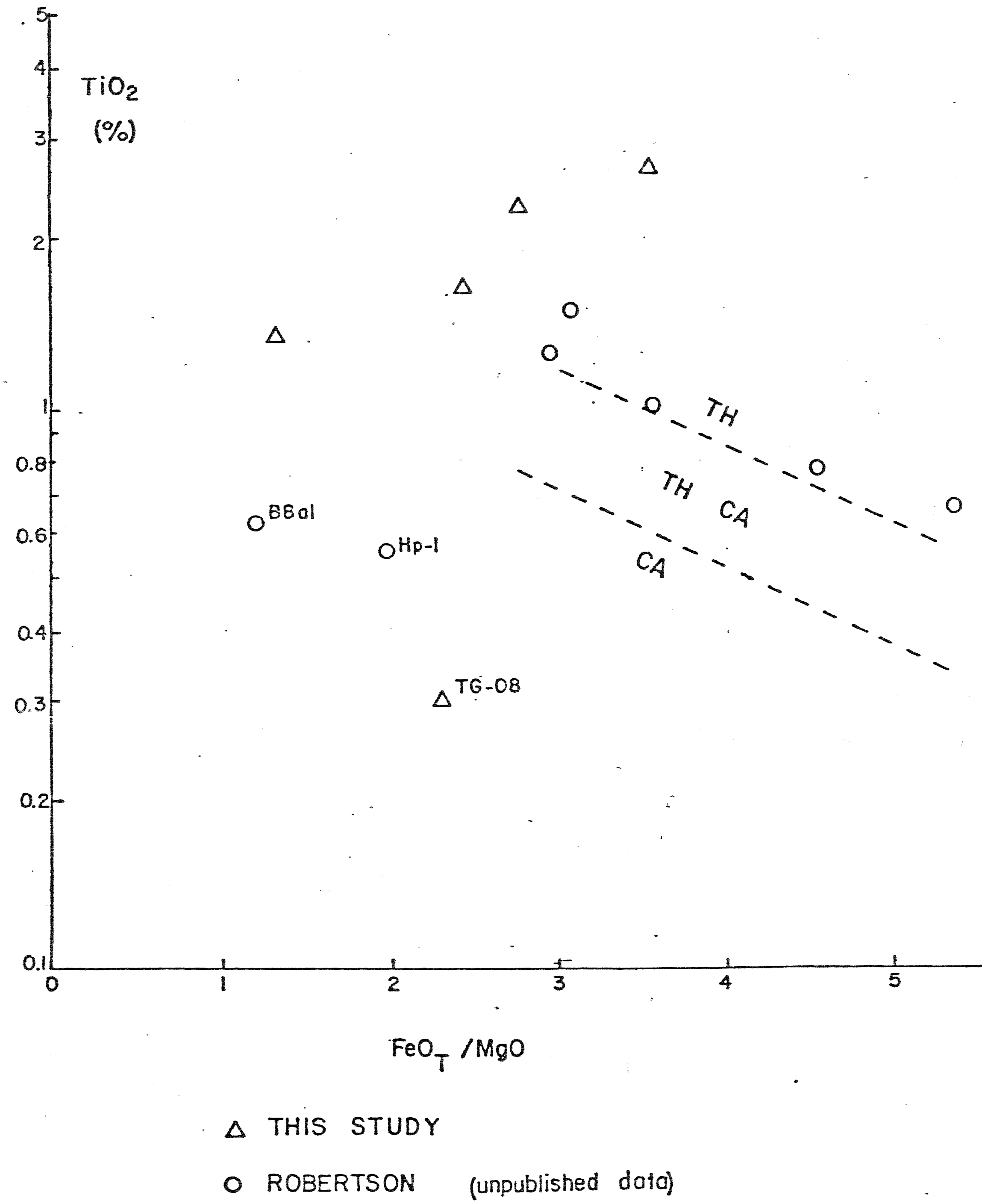


Figure 28

TiO2 vs. FeO(T)/MgO diagram after Miyashiro and Shido (1975). CA Calc-Alkaline; TH tholeiitic (FeO(T) is total iron as FeO).

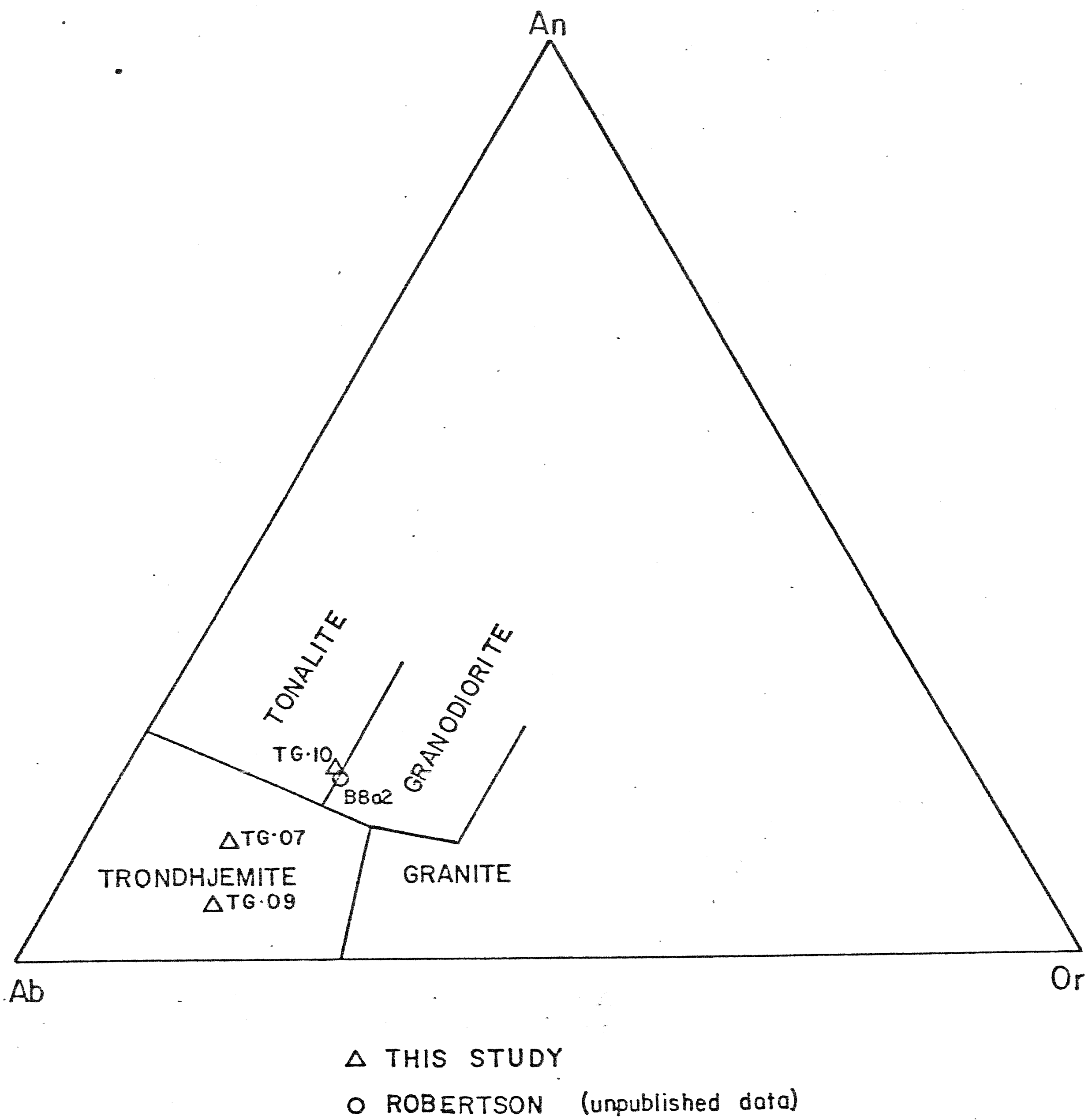


Figure 29

Normative Ab-An-Or diagram with rocks from study area (after Barker, 1979). TG-07 lineated granodiorite; TG-09 granite of Hopewell Lake; TG-10 lineated granodiorite; B8a2 granodiorite of Spring Creek.

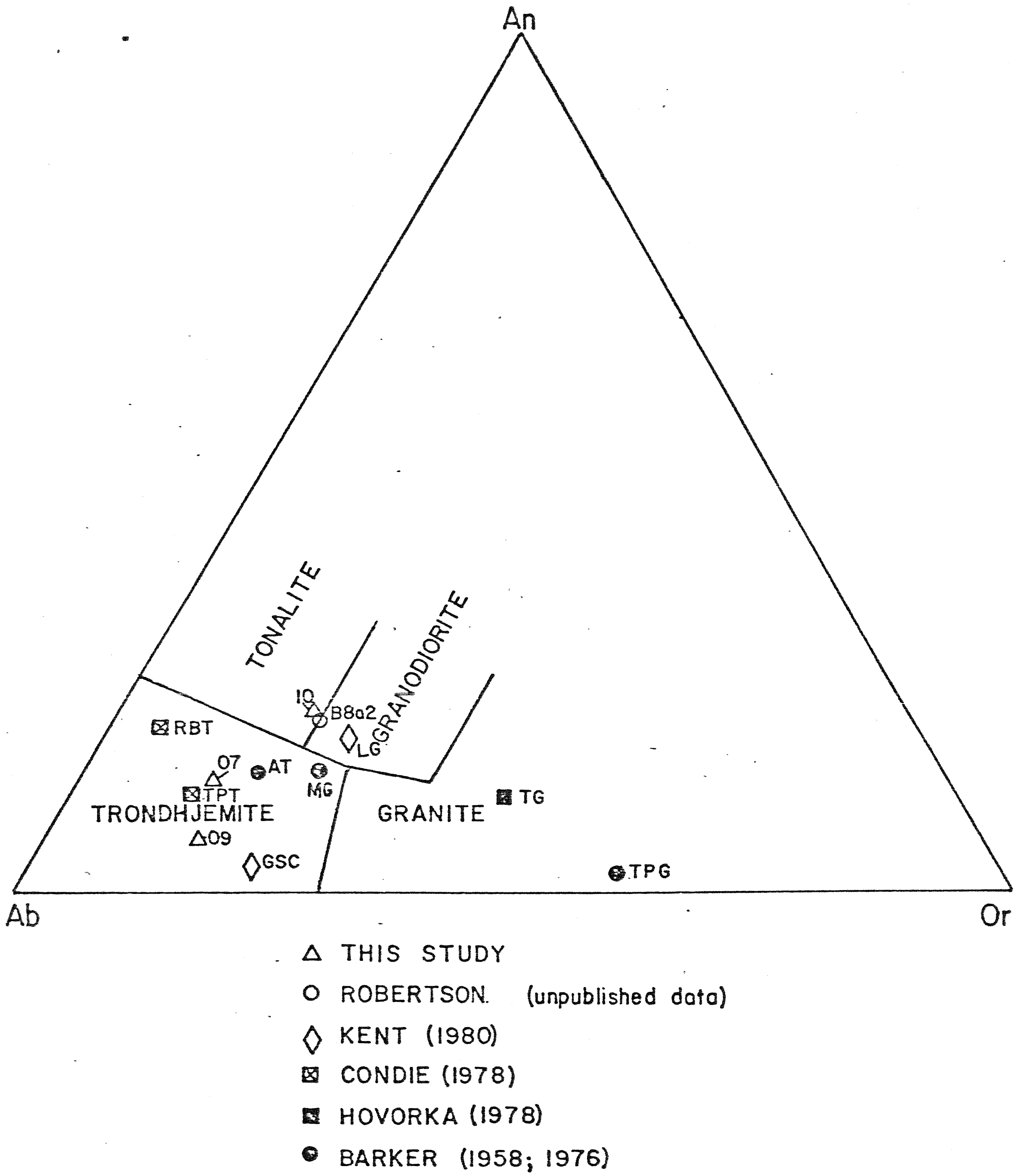


Figure 30

Normative Ab–An–Or diagram a ter Barker (1979) of intrusive rocks in northern Tusas Mountains; 07 lineated granodiorite; 09 granite of Hopewell Lake; 10 lineated granodiorite; B8a2 granodiorite of Spring Creek; L lineated granodiorite; RBT Rio Brazos Trondjhemite; TG Tusas Granite; TPG Tres Piedras granite; MG Maquinita granodiorite; AT Average Trondjhemite Rio Brazos.

Table 2

Geochemical Analysis of Felsic Volcanics and Intrusives

	TG-01	TG-06	TG-07	TG-09	TG-10	*	**	***	BLT-1	BMR	MAG	99192	99000
SiO_2	76.50	76.20	67.10	72.40	68.30	74.57	73.86	66.88	77.50	75.47	68.13	62.35	66.60
TiO_2	0.32	0.28	0.70	0.58	0.60	0.17	0.20	0.57	0.15	0.40	0.26	0.40	0.27
Al_2O_3	12.20	12.00	16.40	14.80	15.20	12.58	13.75	15.66	11.95	11.42	16.81	18.05	17.76
Fe_2O_3	1.44	1.78	2.20	2.08	2.10	1.30	0.78	1.33	1.72	2.26	1.19	1.90	1.77
FeO	0.00	0.16	1.34	0.04	1.83	1.30	1.13	2.59	0.14	0.31	1.56	2.86	1.41
MnO	0.05	0.04	0.06	0.05	0.05	0.05	0.05	0.07	0.05	0.07	0.05	0.07	0.06
MgO	0.12	0.07	1.26	0.16	1.44	0.11	0.26	1.57	0.03	0.30	1.28	2.52	1.08
CaO	0.12	0.11	1.97	0.87	2.77	0.61	0.72	3.56	0.09	0.55	1.88	2.76	0.32
Na_2O	3.36	3.19	6.69	6.60	4.58	4.13	3.51	3.84	3.81	3.29	5.00	5.27	5.01
K_2O	5.15	4.94	1.61	1.75	2.14	4.73	5.13	3.07	3.80	4.90	2.62	3.13	2.07
LOI	0.64	0.61	1.29	1.42	1.07	-	-	-	-	-	-	0.52	1.73
Total	99.90	99.38	100.62	100.15	100.08	99.23	99.13	99.14	99.24	98.97	98.78	99.83	98.08
					C.I.P.W. Mineral Norms (%)								
Q	37.1	38.9	16.0	25.4	25.3	31.1	32.2	21.9	40.8	34.9	22.0	8.6	26.7
C	0.9	1.2	0.1	.5	0.3	-	1.4	-	1.4	-	-	0.9	6.9
Or	30.7	29.5	9.6	10.4	12.8	27.8	30.3	18.3	22.5	28.9	15.5	18.3	12.6
Ab	28.7	27.3	57.0	56.2	39.2	35.1	29.3	32.5	32.4	28.8	42.5	44.9	43.1
An	0.6	0.6	9.8	4.4	13.9	2.0	2.8	16.4	0.2	1.7	9.5	13.9	1.5
En	0.3	0.2	3.2	0.4	3.6	0.3	0.6	3.9	-	-	3.0	6.2	2.8
Fs	-	-	-	-	0.7	0.6	1.1	2.9	-	-	1.6	3.1	2.1
Mt	-	-	2.5	-	3.1	1.9	1.2	1.9	0.1	3.2	1.6	2.8	1.9
Il	0.1	0.4	1.3	0.2	1.2	0.3	0.5	1.1	0.2	0.8	0.5	0.8	0.6
Hm	1.5	1.8	0.5	2.1	-	-	-	-	1.6	-	-	-	-

TG-01 Burned Mountain rhyolite
TG-06 Burned Mountain rhyolite
TG-07 Maquinita granodiorite
TG-09 Tusas granite
TG-10 Maquinita granodiorite
* Average rhyolite (Nockholds, 1954)
** Average granite (Nockholds, 1954)
*** Average granodiorite (Nockholds, 1954)
BLT-1 Burned Mountain rhyolite (Barker and Friedman, 1974)
BMR Burned Mountain rhyolite (Barker, 1958)
MAG Maquinita granodiorite (Barker, 1958)
99192 Three-sample composite Maquinita granodiorite (Kent,1980)
99000 Three sample composite granodiorite of Spring Creek (Kent, 1980)

Table 3

Geochemical Analysis of Mafic Rocks in Study Area

	TG-02	TG-03	TG-04	TG-05	TG-08	*	**	***	99197	90051	99292	MGS
SiO_2	53.40	50.50	44.90	50.70	59.8	50.83	48.36	45.78	50.25	49.79	54.52	44.44
TiO_2	2.28	2.62	1.33	1.63	0.30	2.03	1.32	2.63	0.88	1.11	0.96	1.84
Al_2O_3	19.90	17.90	18.10	19.80	15.40	14.07	16.84	14.64	16.27	18.14	18.52	15.04
Fe_2O_3	3.77	4.12	2.83	3.13	1.80	2.88	2.55	3.16	2.38	2.66	2.46	3.19
FeO	3.61	5.34	5.69	4.13	5.52	9.06	7.92	8.73	8.50	8.35	7.40	9.94
MnO	0.11	0.13	0.13	0.14	0.12	0.18	0.18	0.20	0.15	0.16	0.14	0.23
MgO	2.55	2.57	6.23	2.82	3.12	6.37	8.06	9.39	6.28	4.90	2.35	7.34
CaO	3.43	4.55	7.43	6.66	6.23	10.42	11.07	10.74	9.92	7.05	8.56	8.70
Na_2O	5.51	6.05	3.72	4.87	3.94	2.23	2.26	2.63	3.16	4.07	4.01	1.51
K_2O	2.44	1.31	0.89	1.32	0.11	0.82	0.56	0.95	0.23	1.48	0.39	0.13
LOI	3.58	5.13	8.44	5.67	3.98	–	–	–	1.94	1.29	0.55	–
Total	100.58	100.22	99.69	100.92	100.32				100.8	99.18	100.06	
Q	0.9	–	–	–	16.8	3.5	–	–	–	–	6.1	
C	2.0	–	–	–	–	–	–	–	–	–	–	
Or	14.9	8.2	5.8	8.2	0.7	5.0	3.3	6.1	1.2	9.1	2.4	
Ab	48.1	50.6	31.2	43.3	34.6	18.9	18.9	18.3	27.3	35.4	34.2	
An	17.6	18.7	32.9	29.7	24.9	25.9	34.2	24.7	29.8	28.0	3.6	
Wo	–	2.1	3.1	2.1	3.0	10.3	8.0	10.8	8.5	3.7	4.8	
En	6.5	1.4	2.1	3.8	8.1	15.8	14.0	7.1	15.4	2.0	6.0	
Fs	–	0.5	0.8	1.4	8.7	11.2	7.4	2.9	10.0	1.6	9.0	
Fo	–	3.7	10.5	2.5	–	–	4.3	11.5	0.3	7.4	–	
Fa	–	1.5	4.6	1.0	–	–	2.5	5.0	0.2	6.7	–	
Mt	5.5	6.3	4.5	4.8	2.7	4.2	3.7	4.6	3.7	3.7	3.4	
Il	4.5	5.2	2.8	3.2	0.6	3.8	2.4	5.0	1.7	2.1	1.9	

TG-02	Porphyritic quartz-muscovite-chlorite schist
TG-03	Porphyritic quartz-calcite-chlorite schist
TG-04	Metagabbro
TG-05	Porphyritic muscovite-quartz-chlorite schist
TG-08	Porphyritic undivided Moppin greenschist
*	Average tholeiitic basalt (Nockolds, 1954)
**	Average gabbro (Nockolds, 1954)
***	Average alkali basalt (Nockolds, 1954)
99197	Typical greenschist (Kent, 1980)
90051	Amphibolite (Kent, 1980)
99293	Porphyritic amphibolite (Kent, 1980)
MGS	Moppin Greenschist (Barker, 1958)

Table 4

Geochemical analysis of various rocks from the study area
(Robertson, unpublished data)

(wt. %) Oxide	B4-1	B6-1	B6-2	B7-1	B7-2	B8a1	B8a2	Hp-1	DAT	EAT
SiO2	53.78	53.17	53.38	53.39	53.79	63.94	74.38	60.47	51.4	49.7
TiO2	1.37	0.85	0.84	1.61	0.71	0.68	0.24	0.62	1.9	1.0
Al2O3	18.40	21.03	19.42	15.67	22.50	17.95	14.57	21.32	14.8	14.9
Fe2O3	3.01	2.76	3.01	3.22	2.30	2.34	1.52	2.86	2.1	2.6
FeO	6.24	5.47	6.61	10.54	5.56	2.73	0.00	1.07	8.3	8.8
MnO	0.20	0.18	0.17	0.21	0.08	0.10	0.04	0.08	-	-
MgO	3.01	2.78	1.89	4.34	1.77	4.03	0.37	1.57	6.7	6.3
CaO	7.14	7.40	7.59	6.61	6.32	4.82	2.59	4.53	10.7	9.4
Na2O	3.39	2.54	3.59	3.47	2.59	1.76	4.24	3.72	2.7	2.1
K2O	3.14	3.19	3.14	0.79	4.12	1.57	1.99	4.19	0.2	0.3
P2O5	0.33	0.37	0.40	0.14	0.25	0.08	0.06	0.17	-	-

CIPW Norms

	B4-1	B6-1	B6-2	B7-1	B7-2	B8a1	B8a2	Hp-1
Q	1.60	4.15	0.22	4.89	4.10	30.61	36.17	11.16
C	0.00	0.00	0.00	0.00	2.89	4.78	0.88	2.82
Or	18.55	18.90	18.55	4.67	24.37	9.28	11.76	24.61
Ab	28.68	21.54	30.36	29.36	21.93	14.89	35.88	31.29
An	25.71	34.48	27.59	24.85	29.74	23.39	12.46	21.24
Wo	3.15	0.00	3.10	2.94	0.00	0.00	0.00	0.00
En	7.50	6.94	4.70	10.81	4.41	10.37	0.92	3.89
Fs	7.08	6.71	8.58	14.43	7.29	2.14	0.00	0.00
Mt	4.36	4.01	4.36	4.67	3.34	3.40	0.00	1.90
Il	2.60	1.62	1.60	3.06	1.35	1.29	0.09	1.17

B4-1 Greenschist

B6-1 Greenschist

B6-2 Greenschist

B7-1 Greenschist

B7-2 Greenschist

B8a1 Greenschist near intrusive

B8a2 Granodiorite of Spring Creek

Hp-1 Greenschist near intrusive

DAT Depleated Archean Tholeiite (Condie, 1976)

EAt Enriched Archean Tholeiite (Condie, 1976)

MINERALIZATION

Portions of the area covered by this report contain mineralized Precambrian rocks. The following paragraphs give a brief history of the mining and description of the mineralization and are taken mainly from the work of: Bingler (1968); Benjovsky (1945); Hutchinson (1968); Lindgren and others (1910); and Mcleroy (1972).

The earliest recorded mining activity in the area was the Fairview gold placer operation on Placer Creek, just west and downstream from Hopewell Lake. The richest gravel was found where the valley narrows before passing through the gorge (Eureka Canyon). Over a three year period in the 1870's, this placer is said to have produced $175,000 in gold.

The discovery of alluvial gold prompted a search for lode deposits and resulted in the location of several claims on the numerous veins along Placer Creek. The upper oxidized portions of the veins produced several thousand dollars in gold, silver, copper, and lead. The rapid depletion of the oxidized zone combined with narrow ore shoots and low values saw activity slow by 1890. The turn of the century brought the location of claims, mining activity, and demise to lode deposits along the upper reaches of Rock Creek.

In 1903 a hydraulicing operation was set up in the lower flat southwest of Eureka Canyon on Placer Creek. It proved unsuccessful within a year due to low gold values and problems with the supply of water.

The Amarillo Gold Company acquired the Mineral Point claim in 1935 and constructed a 35-ton/day mill, but the operation proved unprofitable and closed in 1937. Rufus Little of Tesuque, New Mexico acquired most of the patented claims in the area at about this time and still owns most of them.

The Amistad Mining Company set up a dry land dredge in the lower flat after locating four placer claims there in 1964. Failure of the project was attributed to low gold values and the illness of the principle investor.

The past five years has showed a renewed interest in the area with many new claims being staked and several companies both large and small evaluating the area.

Three types of mineralization are present in the study area: hydrothermal sulfide replacement veins, gold-bearing quartz veins, and the placer deposits of alluvial gold. The replacement veins and quartz fissure veins occur in the Maquinita granodiorite, the Tusas granite, the subarkoses, the rhyolite, and rocks of the Moppin series, but only the late hydrothermal quartz veins have been found in the vitreous quartzites.

The replacement veins are zones or veinlike masses of sheared sericitic schist or intrusive impregnated with varying amounts of pyrite, chalcopyrite, galena, sphalerite, and flourite (Bingler, 1968). They range in thickness from less than an inch to about 1.5 feet. The boundaries of many of the veins are indistinct, recognized only by an increase in pyrite and limonite after pyrite, which represent zones of sulfides concentrated within the host rock. In many of the veins the sulfides impregnate schist or intrusive, but some are found in a tough, compact and only weakly fissle schist. The alteration in some veins as observed by Bingler (1968) resulted from the alteration of plagioclase feldspar in the host rock.

Hydrothermal quartz veins are found both associated with the replacement veins and in unaltered country rock. The veins range in thickness from less than an inch to approximately 3 feet and are both concordant and discordant with the layering and/or cleavage in the host rock. Some veins pinch and swell and are discontinuous along strike, while others are tabular and continuous as far as outcrop allows them to be traced. The veins consist of quartz, aggregates and cubic crystals of pyrite, chlorite, and clusters of tourmaline. The gold is associated with the pyrite (Bingler, 1968).

An extensive oxidation mantle can be found below the Tertiary-Precambrian unconformity. It is recognized by the alteration of pyrite, siderite, dolomite, and chlorite in both mineralized and unmineralized host rock to an earthy yellow to reddish brown limonite (Bingler, 1968).

The age of the mineralization has not been determined, but it can be bracketed. The oldest Tertiary unit in the area, the Ritito conglomerate contains cobbles and boulders of mineralized Precambrian rocks indicating the mineralization was pre-Tertiary. All the Precambrian rocks in the area contain the late hydrothermal quartz veins, suggesting the maximum age may be younger than the Precambrian rocks present.

DISCUSSION

COMPARISON WITH EARLY TO MIDDLE PROTEROZOIC ROCKS OF NORTHEAST ARIZONA, SOUTHERN COLORADO, AND NORTHERN NEW MEXICO

The Precambrian rocks of the Tusas Mountains are similar in terms of age, bimodal volcanism, metamorphism, and deformational style to a number of other Precambrian terranes found in northern New Mexico and southern Colorado. In the southern Tusas Mountains (La Madera 7.5 min. quad. Bingler, 1965) Precambrian bimodal volcanics, sediments (quartzites, muscovite-quartzites, kyanite-muscovite schists, and aluminus schists) have been variably metamorphosed to greenschist and amphibolite facies. Three periods of deformation have affected the rocks in the La Madera quadrangle (The first isoclinaly folded the rocks and destroyed the original stratigraphic continuity, the second resulted in NW trending tight to isoclinal folds, and the third consisted of widely spaced axial-plane fracture and slip cleavage trending generally E-W with steep dips.

In the Needle Mountains of southwestern Colorado Barker, (1969a) reports mafic, intermediate, and acidic volcanic rocks associated with graywacke, quartzites, and impure sandstones (Irving Formation) which are overlain by a sequence of bimodal volcanic or plutonic rocks (Twighlight Gneiss), all of which have been metamorphosed and deformed

(N to NE tending folds) and then intruded by a post tectonic granitic intrusives (1.7-1.8b.y. Tenmile Granite). After a period of profound erosion quartzite, mud, minor silt and conglomerates were deposited (Uncomphahgre Formation) and were subsequently metamorphosed to lower amphibolite facies and deformed (E to SE trending folds) along with the underlying rocks. Intrusion of the post tectonic Eolus granite followed by the Trimble granite were the last preserved Precambrian events (1.45 to 1.65 b.y.).

Precambrian supracrustal rocks in the Salida area of south-central Colorado consist of sediments and bimodal volcanics which have been metamorphosed to the middle amphibolite facies (Boardman, 1976). A post-metamorphic quartz monzanite (dated at 1.65-1.70 b.y.) intrudes these supracrustal rocks.

In the Dubois greenstone succession of central Colorado Condie and Nuter (1980, in press) report bimodal volcanics and late to post tectonic "granitic" intrusives metamorphosed to the middle to upper amphibolite facies (Rb/Sr dates of 1.65 to 1.70 b.y.).

The Taos region of northern New Mexico contains bimodal volcanics and sedimentary rocks (quartzofeldspathic paragneisses and quartzites) which have been intruded by tonalite-trondhjemite or granite all of which have been metamorphosed to amphibolite facies. The stratigraphic relationships of the supracrustals are unknown (Condie, 1979).

To the southeast of the Taos area in the Picuris Mountains, Neilsen and Scott (1979) report Precambrian bimodal volcanics interbedded with sedimentary rocks metamorphosed to amphibolite facies. Long (1976), recognized four intrusive plutons in the Embudo complex of the Picuris range. The oldest being dated at 1673 m.y. They also report that four distinct deformational episodes have effected the area (the first isoclinaly folded the rocks in the region, the second formed tight to near isoclinal folds which tend E-W and plunge at 20 to 30 degrees to the west, the third episode of deformation resulted in deformation of the F2 axis by an axial-plane cleavage trending N 20 W, and the fourth deformation resulted in local ductile offsets of earlier surfaces about a calculated N 66 E axial surface).

In the Truchas Peaks area, Grambling (1979) reports interbedded bimodal volcanics (1.7 to 1.8 b.y.) and sediments (quartzites, high aluminus pelites, and quartz-muscovite schists) metamorphosed to the amphibolite facies. Two periods of deformation have effected these rocks, the first forming east-trending tight to isoclinal folds which in turn have been folded by a north-trending set of open folds that plunge to the south.

Further to the south in the Pecos area Robertson and Moench (1979) and Robertson (1981) report bimodal volcanics (1.71 to 1.72 b.y.) overlying quartzites, and, in turn, are overlain by sedimentary rocks (shales, volcaniclastic sediments, metasandstone, and iron formation). They delineated two suites of intrusive rocks: 1) amphibolites, quartz diorites, and trondhjemites; and 2) granites to tonalites. They suggested at least two periods of deformation had effected the rocks (the first resulted in E-W trending tight to isoclinal folds and the second NE trending folds) and variable metamorphism to greenschist and amphibolite facies.

In the Jerome-Prescott area of central Arizona, Precambrian andesites, basalts and rhyolites and minor associated sediments have been documented (Anderson and Silver, 1976). This series has been dated at 1.7 to 1.8 b.y. (U/Pb zircons). Granodiorites and a quartz diorite intrude the supracrustal sequence.

TECTONIC SETTING

Any discussion of tectonic settings for the present study area and northern Tusas Mountains must be tempered by a consideration of the geologic conditions or constraints displayed by that area. Kent (1980) proposed a list of constraints (indicated in the following list by an asterisk) which can be either condensed or expanded on the basis of the data from the present study. Each constraint is explained and the list is followed by a brief discussion of reasonable and/or possible tectonic settings.

Constraints:

1) Bimodal Volcanism*. Precambrian volcanic rocks in the Tusas Mountain area are compositionaly bimodal. Rhyolites appear to be calc-alkaline whereas the mafic rocks most closely resemble tholeiitic basalts.
2) Feldspathic Metasediment Source. The problem of a source for the quartz and feldspars found in the feldspathic metasedimentary sequence must be addressed. One possibility, is weathering of the Burned Mountain metarhyolite. It does not seem possible however that this felsic volcanic could yield the amount of quartz found in the metasubarkoses. It is possible, however that the metarhyolite as seen in the presen study area, lies on the fringes of a volcanic center, which although seen nowhere today might have been thick enough to supply the quartz and feldspar found in the metasubarkoses.
3) Quartzite Source*. A source for the quartz sands that accumulated to form the vitreous quartzites must be discussed. It has been suggested (Donaldson and Ojankangas, 1977) that quartz in quartzites could have come from vein quartz, recrystallized chert, phenocrysts from felsic volcanics, and granitic rocks.

The volumes of quartz veins and chert required to generate the amount of quartz sand are not present. To generate the sand from felsic volcanics or granitic rocks would require that these sources have undergone intense weathering, recycling, and/or reworking. Current thinking, Wobus (personal communication, 1981) is that all quartzite in the Tusas Mountains is younger than the volcanic rocks present, although there is no good evidence to date as to how much younger. Therefore, plenty of time to erode and rework, feldspathic sediments, rhyolite, and/or some other source into ultimately pure quartzite could have elapsed.

4) Relationship between Feldspathic Metasediments-Quartzites and Volcanics*. The association of stable continental shelf-type sediments and mafic and felsic volcanics must be explained. Grambling (1979) suggest that the quartzites in the Truchas Peaks area are interlayered and may be interfingered with the metavolcanic rocks. In this area the quartz-rich clastic metasediments overlie most of the volcanics and interfinger slightly with the Burned Mountain metarhyolite, but are mainly younger.

5) Age of Rocks *. In a regional sense the ages of Precambrian rocks young to the south in New Mexico. This younging may only be apparent and due to lack of zircon dates especially in metavolcanics (most dates

are from plutonic rocks). If real, however, there is an age boundary, which although not well defined runs northeastly across New Mexico separating 1690 to 1780 m.y. old rocks in the north from 1610 to 1680 m.y. old rocks in the south. Table 5 is a list of known ages of rocks in the northern Tusas Mountains.

6) Basement Problem*. Nowhere in this study area or in northern New Mexico or southern Colorado are there any Archean rocks. This raises the question as to what the volcanics and the sediments were deposited on or what there source may have been. Kent (1980) reports that isotopic ratios of plutonic rocks of central and southern New Mexico typically have low Sr 87/86 initial ratios. If these intrusives were produced by the partial melting of lower crust then such low initial ratios demand that the crustal source was not in existence for more than 200 m.y. before melting began. Initial ratios of the post-tectonic plutons of northern New Mexico, however, have high initial ratios often exceeding .710 suggesting crustal source for these rocks. She also notes that Rb-Sr data for syn-tectonic intrusive in northern New Mexico have not been reported in the literature.

7) Precambrian Deformation*. Discussion of any tectonic history for the Precambrian of the Tusas Mountains must include an explanation for multiple periods of compressional deformation.

Table 5

Ages of Precambrian Rocks

Northern Tusas Mountains*

Age	Rock Name	Type of Date	Reference
1715 to 1765 m.y.	Burned Mountain Rhyolite	U/Pb Zircon	Barker and Friedman (1974)
1675 to 1715 m.y.	Maquinita Granodiorite (lineated granodiorite)	U/Pb Zircon	Barker and Friedman (1974)
1661 m.y.	Tres Piedras Granite (granite of Hopewell Lake)	Rb/Sr whole rock	Maxon (1976)

*All ages have been corrected for new decay constants

8) Precambrian Metamorphism*. Any discussion of a geologic history for the Tusas Mountains must include some method of achieving the metamorphic grades present.

9) Trondhjemites*. Precambrian trondjhemitic intrusives are found in northern New Mexico and southern Colorado.

10) Lack of subaqueous features in Moppin mafic series. In the Burned Mountain area no iron formation was found or were any pillow structures recognized in the mafic rocks. These features are however present elsewhere in the northern Tusas Mountains. The lack of these features in the present study area may be due to: a) some combination of deformation and folding that concealed the iron formation and obscured or destroyed any pillow structures; b) lack of formation of these features due to the area being subareal; or c) obliteration by later intrusives which may have assimilated the iron formation or some pillow structures.

Discussion of Tectonic Settings

The Precambrian supracrustal rocks in the Burned Mountain area are best explained by the presence of an extensional environment. A continental rift, aulacogen, or a back arc basin can all produce bimodal volcanism (basalts and rhyolites) and the types of sediments found in the study area (subarkoses, quartzites, and minor graywacke and shales). Any rift would have been near sea level as both subaqueous and fluvial features are found in the area. However no evidence for extensional faulting or for earlier continental crust has been found in southern Colorado and northern New Mexico Precambrian Terraines. This raises the question of what was being rifted if an extensional environment was present. Both regional metamorphism and trondhjemite formation can occur in extensional settings, although they are not limited to them. Deformation, particularly compressional varieties is not so easily explained by rifting or any extensional environment. A compressional environment, such as a convergent plate boundry, explains deformational style which followed deposition of the supracrustal sequence.

However, a convergent plate boundry typically produces calc-alkaline volcanic rocks including large volumes of andesites and graywackes instead of subarkoses, mature quartzites, and bimodal volcanics. In addition, they commonly contain ophiolite suites and thrust faults neither of which has been documented in northern New Mexico or Southern Colorado. There are, however, calc-alkaline, andesite-rich, and graywacke suites in northeastern Arizona in the Jerome-Prescott area, and these rocks have also been dated at 1.7 to 1.8 b.y.

One possible tectonic setting for the Burned Mountain area is that of a continental rift that opened in the Precambrian crust near a plate margin (an aulacogen ?), erupting bimodal volcanics and depositing feldspathic and quartz-rich sediments. The continental margin soon thereafter became convergent, closing the rift causing deformation, metamorphism, +/- intrusive activity (calc-alkaline volcanism ?). A second possible tectonic setting calls for a back arc basin that was first opened and then closed as convergence along the continental margin progressed.

SUMMARY OF PRECAMBRIAN GEOLOGIC HISTORY
IN THE BURNED MOUNTAIN AREA

1) Eruption of mafic flows and emplacement of shallow mafic intrusives accompanied by deposition of volcaniclastic sediments derived from a mafic source, probably the mafic igneous rocks

2) Mafic volcanism ceases possibly accompanied by minor uplift and erosion of the mafic succession (Moppin series).

3) Eruption of felsic volcanics dated at 1715 to 1765 (Burned Mountain rhyolite), accompanied, more or less simultaneously, by deposition of subarkosic conglomerate lenses.

4) Deposition of subarkoses and mature sandstone. The exact relationship between the subarkoses and the quartzites is not yet known, however in this study the quartzites are thought to be gradationaly above the subarkoses.

5) Compressional event which produced tight to isoclinal northwest trending folds and axial-plain foliation S1.

6) Onset of compressional event that produced tight to near-isoclinal northwest trending folds (Hopewell anticline and Kiowa syncline) and well developed axial-plain foliation S2.

7) Intrusion of syntectonic granodiorites dated at 1675 to 1715 m.y. by Barker and Friedman (1974) (lineated granodiorite and granodiorite of Spring Creek ?).

8) Intrusion of late to post tectonic granite dated at 1661 m.y. (granite of Hopewell Lake).

9) Post tectonic thermal event 1490 m.y. (Maxon, 1976).

10) Intrusion of quartz veins and metasomatism dated at 1425m.y. (Gressens, 1975 and Long, 1972).

11) Late thermal event +/- local deformation dated at 1350 m.y. (Gressens, 1975 and Long, 1972).

SUMMARY AND CONCLUSIONS

Precambrian rocks in the Burned Mountain area crop out poorly from underneath Tertiary and Quaternary deposits. They only crop out over approximately ten percent of the study area. The oldest rocks present are a series of mafic volcanics, and volcaniclastic sediments (quartz, muscovite, chlorite +/- plagioclase and calcite schist, mafic conglomerate, metagabbro and chlorite, muscovite schist) called the Moppin series. Unconformably overlying the mafic sequence is the Burned Mountain metarhyolite which has been dated at 1715 to 1765 m.y. Overlying and interbedded with the Burned Mountain metarhyolite is a sequence of feldspathic metasedimentary rocks (subarkoses, subarkosic conglomerates, and minor microcline-muscovite-quartz schist, banded quartzite, and shale). These rocks represent a fundamental change in the source and/or the source area for sediments in the area. Separated from the feldspathic metasediments by the northwest trending Tertiary-age (latest movement) Vallecitos Valley fault is a thick sequence of vitreous quartzites, tentatively thought to overly the feldspathic metasediments. However, elsewhere in the Tusas Mountains these rocks or other quartzites have been interpreted as being older than the above supracrustal sequence.

Three periods of deformation have effected part or all of the Precambrian rocks in the Burned Mountain area. The first episode of deformation predates the lineated granodiorite and resulted in tight to isoclinal folds trending N 30-40 W. The second episode of deformation refolds the above folds and produced the well developed axial-plane foliation seen in some of the rocks in the area. The folds produced by this deformation trend N 65-80 W and plunge upto 55 degrees to the west. The lineated granodiorite was intruded during this period of deformation. The granite of Hopewell lake was intruded at the very end of this deformational episode, after the lineated granodiorite. The third period of deformation produced a kink banding or widely spaced crenulation cleavage which trends N 20 W to N 20 E and dips from 50 E to 60 W. Metamorphism (lower greenschist facies) of the Precambrian rocks in the area accompanied the intrusive events as no hornfels or contact metamorphic assemblages were observed.

The Precambrian rocks in the Tusas Mountains are similar to other Precambrian terranes in southern Colorado and northern New mexico in that they are approximately the same age, have undergone similar metamorphism (greenschist to amphibolite facies), contain similar lithologies, and in that the have undergone multiple periods of deformation. They do, however, differ fundamentally from similar age rocks in northeast Arizona.

A tectonic setting characterized by early extensional and later compressional environments is needed to explain the Precambrian geology of the Burned Mountain area. Either a back arc basin which has been compressed against a continent or a near-plate-boundary continental rift (aulacogen ?) which has been compressed could produce such a setting.

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APPENDIXES

APPENDIX I

ROCK DESCRIPTION

MOPPIN SERIES

The Moppin series crops out along a northwest trending belt from the southeast flank of Jawbone Mountain (north of study area) to east of Tusas Mountain where it is covered by Tertiary rocks. Nowhere is the base of the series exposed. It has been intruded by a granodiorite and a later granite that both contain xenoliths of the Moppin series rocks. It is unconformably overlain by interbedded feldspathic sediments and/or a porphyritic felsic schist (Burned Mountain Rhyolite).

Rocks of the Moppin series crop out poorly except along valley walls (see Fig. 31). Dense vegetation and lack of many continuous, distinctive units makes correlation from outcrop to outcrop difficult if not impossible. Metamorphism is low grade as evidenced by the mineral assemblage chlorite, muscovited, albite, quartz, +/- epidote, +/- clinozoisite. Magnetite octahedra and iron-carbonate staining are common. The rocks are poorly to well foliated, but primary textures and structures are partially preserved.

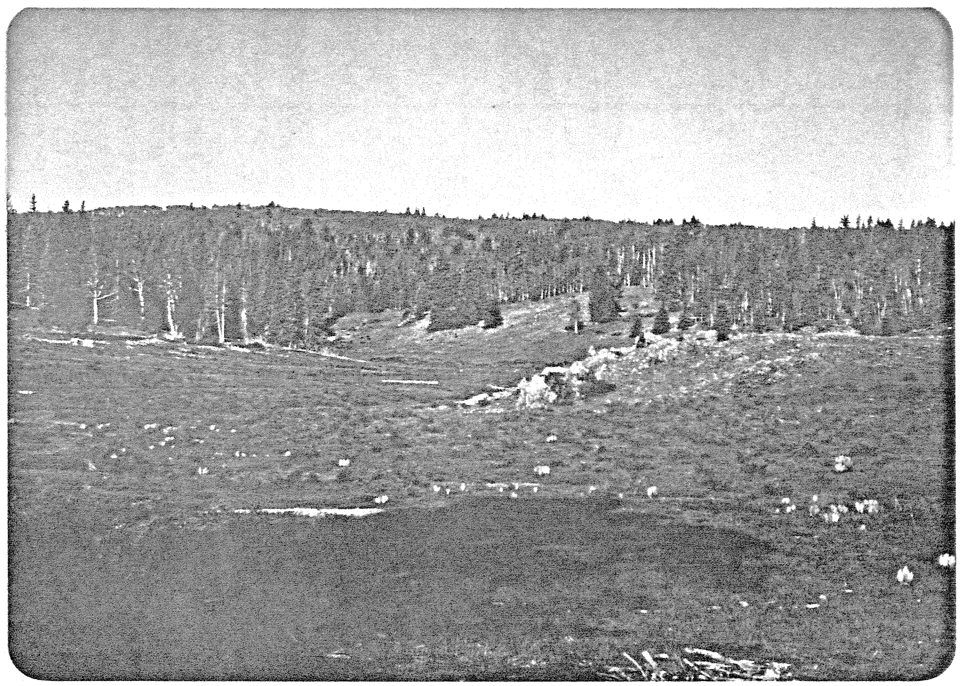


Figure 31

Photograph of typical Moppin greenschist outcrop along Rock Creek, section 16, T.28N. R.7E.

QUARTZ-MUSCOVITE-CHLORITE SCHIST

The most abundant rock of the Moppin series is a well foliated quartz-muscovite-chlorite schist. It is found in the eastern portions of the field area (Sec. 15, 16, and 22, T28N R7E) along the upper reaches of Rock Creek and Sheep Gulch.

This rock breaks along cleavage planes and is dark green to green on fresh surfaces. Weathered surfaces are greenish-gray to green and iron-carbonate staining is not uncommon. Magnetite octahedra are commonly visible to the unaided eye.

The relationship of this rock to other units in the Moppin series is difficult to interpret, due to lack of stratigraphic markers. Stretched and/or sheared knots of muscovite, calcite, and epidote are common. Slightly altered plagioclase megacrysts are common and can be found both subparallel to foliation and randomly oriented. Up to 45 percent of some of these schists can be composed of megacrysts.

In thin section chlorite makes up 25 to 50 percent of the rock, muscovite (including sericite) 15 to 35 percent, calcite 10 to 25 percent, plagioclase (including megacrysts) 10 to 45 percent, and quartz 10 to 30 percent. Epidote, actinolite/tremolite, and clinozoisite are common in accessory amounts. The plagioclase was determined to be albite-oligoclase (an 5 to 25). The chlorite grains are subparallel and usually .5 mm to 1 mm in length. Plagioclase crystals range from .5 mm to 12 mm (megacrysts) in length with the megacrysts often badly sericitized or epidotized. Foliation is the result of the alignment of chlorite and muscovite crystals which bend around the megacrysts when present.

CONGLOMERATIC MOPPIN SCHIST

A mafic conglomeratic unit is a variation of the quartz-muscovite-chlorite schist. It comprises 1 to 3 percent of the Moppin series and crops out in the NW 1/4 of Sec. 16, T28N R7E. This unit is approximately 3 meters thick. It is well foliated and crops out as rounded, elongate knolls. Aphanitic phyllite fragments of a light gray in color are contained in a dark green to greenish-gray aphanitic matrix. The phyllite fragments are flattened and stretched to form a lineation in the steeply deeping plane of foliation. Fragments make up as much as 45 percent of the rock and range from a few mm up to 12 cm in length.

In thin section the matrix is made up of 40 to 60 percent chlorite, 20 to 30 percent muscovite, 10 to 20 percent quartz. Plagioclase and epidote are common as accessory minerals. The fragments are 50 to 60 percent muscovite, 20 to 30 percent quartz , and 5 to 10 percent each of epidote and chlorite. Magnetite is a common accessory mineral in the matrix. Chlorite and muscovite crystals (.5 to 1 mm in length) are aligned in both the matrix and fragments giving the rock its foliation (see Fig. 32).

MOPPIN FELSIC SCHIST

The second most abundant rock type in the Moppin series is a porphyritic felsic schist. It occurs in one stratigraphic position near the northern most exposures of the Moppin series. The best exposures of this schist are along Rock Creek in section 8, T28N R7E. It outcrops poorly and is usually only found as float. The rare outcrop is usually angular, found below grass level and weathers brownish-red to redish-pink. It is moderately to well foliated and breaks along these foliation planes. Fresh rock is pink to reddish-pink. Rounded, blue quartz phenocrysts, up to .5 cm in diameter are prominent in an aphanitic groundmass and make up 10 to 25 percent of the rock. Small (1 to 2 mm) elongate light gray to greenish-gray lenses comprise approximately 5 to 15 percent of the schist.

Thin section examination reveals that the 2 to 5 mm quartz phenocrysts are slightly embayed and often recrystalized to aggregates of smaller crystals. The light

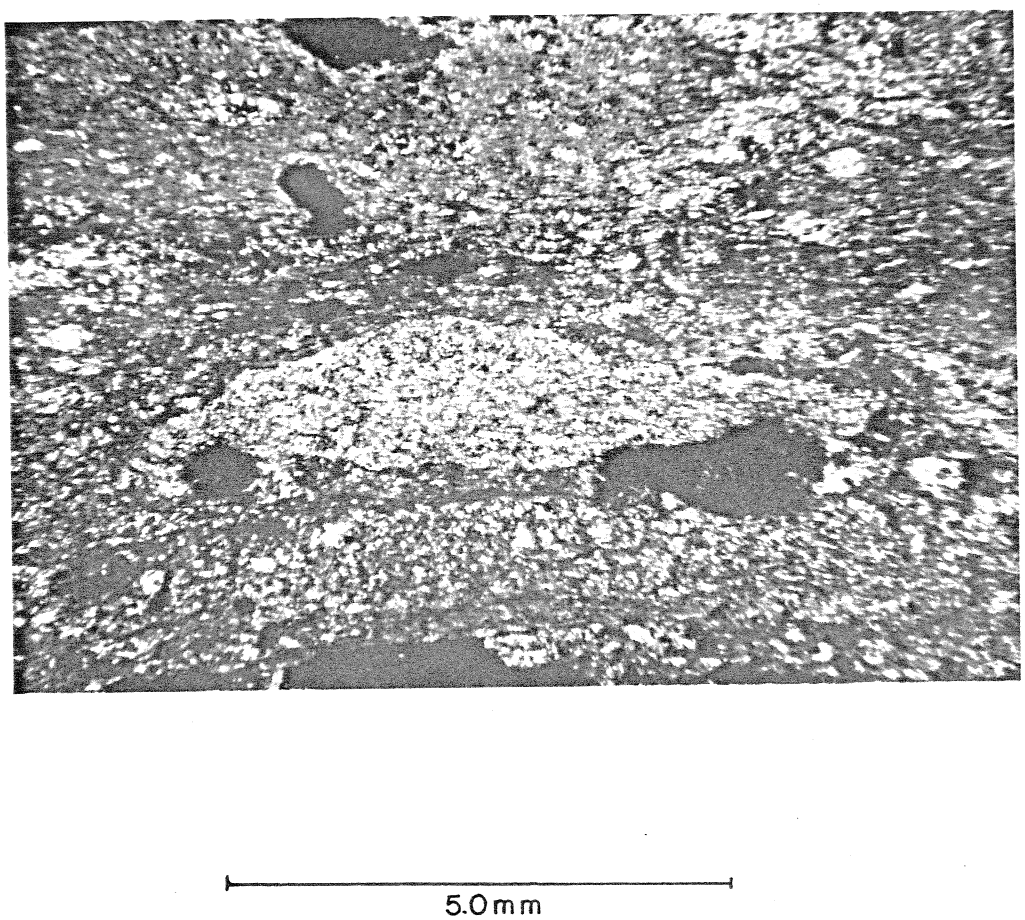


Figure 32

Photomicrograph of Mafic Metaconglomerate
From along Rock Creek, section 16, T.28N. R.7E.
(10X and crossed Nicols)

colored lenses are composed of muscovite and chlorite or badly sericitized plagioclase. The matrix is made up of quartz, and muscovite in roughly equal amounts, +/- epidote. The quartz crystals are slightly elongate and form planes separated by parallel planes muscovite crystals, resulting in a compositional banding (Fig. 33). Matrix material wraps around the megacrysts (phenocrysts) and fragments. Fractures are filled with muscovite and minor epidote.

METADIABASE

This porphyritic dark-green to gray-green rock with relict diabasic texture is neither abundant or continuous enough to map. It is found only in sparse discontinuous low-rounded knolls and as float along Rock Creek in sections 15 and 16 T28N R7E. It is weakly foliated and thought to be intrusive due to its random stratigraphic occurrence and discontinuity. Lack of stratigraphic markers in encompassing rocks may be an explanation for no observed crosscutting contacts beteen this rock and the surrounding greenschists. Altered 3 to 10 mm megacrysts (phenocrysts) of a light-gray material are contained in an aphanitic dark green to gray matrix. The rock breaks with along the weakly-defined foliation planes.

Thin section examination reveals the megacrysts (phenocrysts) are now largely calcite, epidote, and sericite, but were probably originally plagioclase as

Figure 33

Photomicrograph of felsic schist (distal Burned Mountain ?).
Sample from along Rock Creek section 15, T.28N. R.7E.
(10X and crossed Nicols)

remnant crystal shapes and rare altered plagioclase phenocrysts suggests. The rock consists of 30 to 40 percent chlorite, 15 to 25 percent calcite, 10 to 20 percent quartz, and 10 to 15 percent muscovite (inc. sericite). Epidote, clinozoisite, and plagioclase are common accessory minerals. The plagioclase was too altered for identification. Calcite and quartz grains were 2 to 4 mm in diameter. The chlorite and muscovite exhibit a very weak subparallel alignment resulting in the weak foliation. Magnetite and hematite are not uncommon accessory minerals.

CHLORITE-QUARTZ-MUSCOVITE SCHIST

In the southern most exposures of the Moppin series a thin (1 m ?), discontinuous unit of well-foliated chlorite-quartz-muscovite schist crops out only rarely. It can be found in the SE 1/4 of section 16, T.28N. R.7E. as float an occasionally in small angular outcrops at ground level. A prospect pit in the area is the best exposure. The limited outcrops and structural complications make contact relationships impossible to determine. It is light-gray to silver-gray in color and breaks along cleavage planes. The rock reflects sunlight with what is almost a phyllitic luster. Handspecimans often contain magnetite octahedra and the rock is pretty much equigranular with chlorite, quartz and muscovite being identifiable.

BURNED MOUNTAIN METARHYOLITE

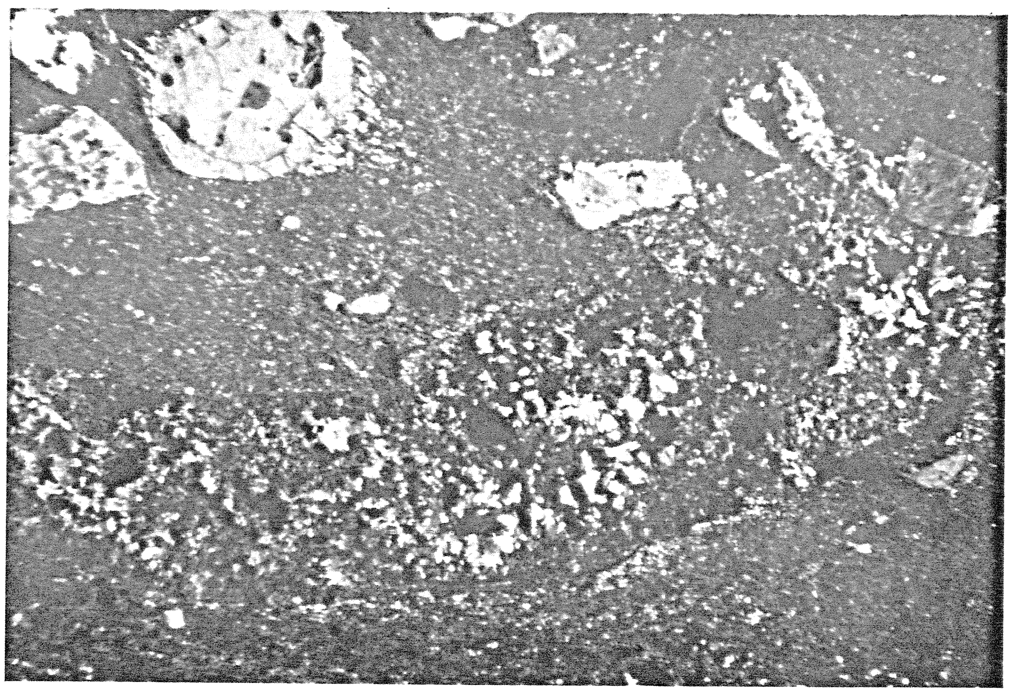
Unconformably overling the Moppin series and interbedded near the base of the with feldspathic metasediments is a porphyritic felsic schist, called by Barker (1958) and in this text the Burned Mountain metarhyolite. It outcrops from one end of the study area to the other in one stratigraphic horizon. Along Sheep Gulch (Sec. 22, T28N R7E), Rock Creek (Sec. 16 and 21, T28N R7E), and south of Burned Mountain (Sec. 9, T.28N. R.7E.) multiple horizons are present due to folding. The thickness varies from 10 meters to approximately 100 meters either because of tectonic related thining, thinning due to distance from the source, and/or onlap to a geographical high.

This rhyolite outcrops with brick-red to pink weathered surfaces, is massive to weakly foliated and breaks with uneven surfaces. It crops out as prominent angular to rounded knolls or ridges. Relict phenocrysts of rounded, blue quartz stand out on weathered surfaces and are roughly equal in number to light-gray to white potassium feldspar phenocrysts. The combined phenocrysts make up approximately 40 percent of the rock and are contained in an aphanitic groundmass. Light-gray to reddish-pink, phenocryst bearing aphanitic lenses up to to 3 meters long are interpreted as flattened pumice fragments (see Fig. 34 and 35). Rounded, red chert pebbles accompany the pumice fragments. These textures and structures are best exposed on the south side of Burned Mountain in Section 8, T28N R7E.

Thin section examination reveals the quartz phenocrysts are slightly embayed and some have recrystalized into aggregates of smaller crystals. The potassium feldspar phenocrysts rarely exhibit resorbed boundaries and are now microcline, but were probably originaly sanidine or orthoclase as their subhedral shapes suggest. These phenocryst range in size from 1 mm up to 1 cm and the quartz phenocrysts from 1mm up to 6 or 8 mm. The aphanitic matrix is composed of 35 to 50 percent quartz, 35 to 45 percent microcline, 10 to 15 percent sericite +/- minor epidote and plagioclase. Magnetite, hematite, and apatite are rare accessory minerals.

Figure 34

Pumice fragment in Burned Mountain metarhyolite (eutaxitic texture). From Top of Burned Mountain, section 8, T.28N. R.7E.



5.0 mm

Figure 35

Photomicrograph of Pumice Fragment (?)
(10X and crossed Nicols)

FELDSPATHIC METASEDIMENTS

Interbedded with the Burned Mountain rhyolite and in places lying directly on the Moppin series is a sequence of feldspathic metasediments. Four distinct rock types can be recognized in the area mapped as metasubarkose. The metasubarkoses proper are estimated to comprise 70 to 85 percent of the feldspathic metasediments, pebble conglomerates 10 t0 15 percent, microcline-muscovite-quartz schist 2 to 4 percent, banded quartzite 2 to 3 percent, and a quartz-muscovite schist 2 to 3 percent. All these rocks are massive to well foliated and outcrop as rounded knolls and ridges along valley walls and rarely along ridges.

METASUBARKOSES

Interbedded with and overlying the Burned Mountain metarhyolite is a sequence of metasubarkoses as classified by Pettijohn and others (1973). They are massive to weakly foliated, dark-gray to brownish-gray, often crossbedded, and rarely exhibit graded bedding. Lenses of metaconglomerates are found throughout the sequence but are most common near the base. The crossbedding is enhanced by the concentration of magnetite grains on bedding planes.

This rock can be found outcroping across the entire area as massive, smooth, rounded to angular knolls and bluffs. Quartz grains stand out in relief on weathered surfaces and the rock breaks along weakly-developed foliation planes or with an uneven surface. Fresh surfaces are a light silver to silver-gray.

In thin section the rock is comprised of 70 to 85 percent quartz, 10 to 15 percent sericite, and 5 to 10 percent orthoclase. Magnetite and hematite are common accessory minerals and may make up 5 percent of the rock. It is poorly to moderately sorted and the average grain size is 1 to 2 mm, but with a wide range. The quartz grains are subrounded to angular and are rarely slightly elongate parallel to foliation which is also a result of subparallel alignment of muscovite and sericite crystals.

The metaconglomerate lenses contain pebbles and cobbles of rhyolite (see Fig. 36), red chert, white vein quartz, muscovite-chlorite schist, and phyllite fragments in a subarkosic matrix. The rhyolite, chert, and quartz fragments are angular to sub-rounded and the phyllite fragments are usually stretched in the plane of foliation resulting in a lineation. The phyllite fragments often exhibit a foliation different to that in the metasubarkosic matrix.

MICROCLINE-MUSCOVITE-QUARTZ SCHIST

Near the base of the feldspathic metasediment sequence and interbedded with metasubarkoses and metaconglomerate lenses is a fine grained microcline-muscovite-quartz

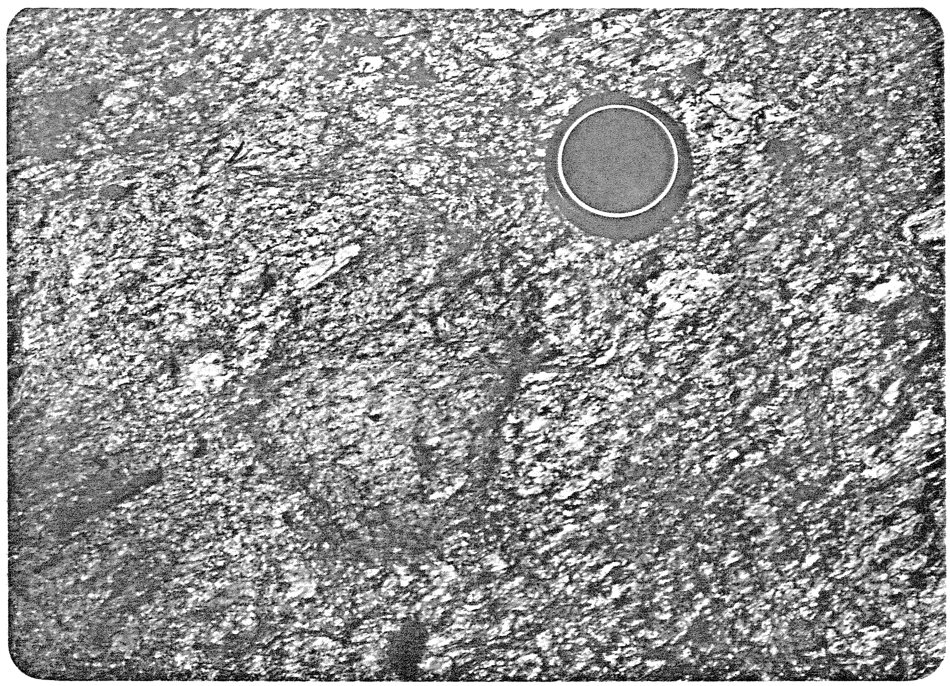


Figure 36

Cobble of Burned Mountain Metarhyolite in Subarkosic Conglomerate From east of Burned Mountain, section 9, T.28N. R.7E.

schist is uncommon. Outcrops of this unit are sparse and discontinuous with the best exposures being in section 9 T28N R7E along Rock Creek. It outcrops as rounded elongate knolls or as bluffs along stream banks and is massive to moderately foliated. It weathers gray to brownish-gray. It breaks along foliation planes and is light-gray on fresh surfaces.

Thin section examination shows that 1/2 to 1 mm grains of slightly embayed quartz make up 25 to 35 percent of the rock, 10 to 20 percent is fine grained quartz, 25 to 35 percent is sericite, 10 to 15 percent is microcline. Epidote, hematite, and magnetite are common in accessory amounts. The quartz and microcline grains are surrounded by fine grained quartz and sericite (1 mm) that exhibits a subparallel to random orientation.

BANDED QUARTZITE

Interbedded with the metasubarkoses, but above the Burned Mountain rhyolite an uncommon, finely-bedded quartzite occurs. Its found only rarely as smooth, angular to rounded, reddish to brown outcrops, but more commonly as float. It is nowhere thicker than 1 meter and always associated with an equally rare quartz-muscovite schist. The banding is a result of concentrations of magnetite and/or hematite in varying amounts along what appears to be bedding planes. The bedding is on the order of millimeters to centimeters. The unit appears conformable to the surrounding metasubarkoses and quartz-muscovite schist. Due to structural complications and poor outcrop it is only tentatively thought to occupy only one stratigraphic position.

QUARTZ-MUSCOVITE SCHIST

As mentioned, accompanying the banded quartzites is a fine grained quartz-muscovite schist. This unit is nowhere thicker than one meter and is light gray to gray on weathered surfaces. It is well foliated and breaks along the well developed cleavage planes. It is most commonly found as float and very rarely as well foliated outcrops. Quartz, chlorite, and muscovite are the most common minerals.

VITREOUS QUARTZITES

In fault contact with the feldspathic metasediments are purplish-gray to gray vitreous quartzites. They outcrop in bold, smooth, massive to moderately foliated, rounded knolls and bluffs. Jointing is common as are quartz veins. Crossbedding is well developed and graded bedding is common. Their true relation to metasubarkoses is unknown, but they are in probably younger. The quartzites have been described detail by Barker (1958) and Bingler (1965). The reader should refer to these references for further descriptions.

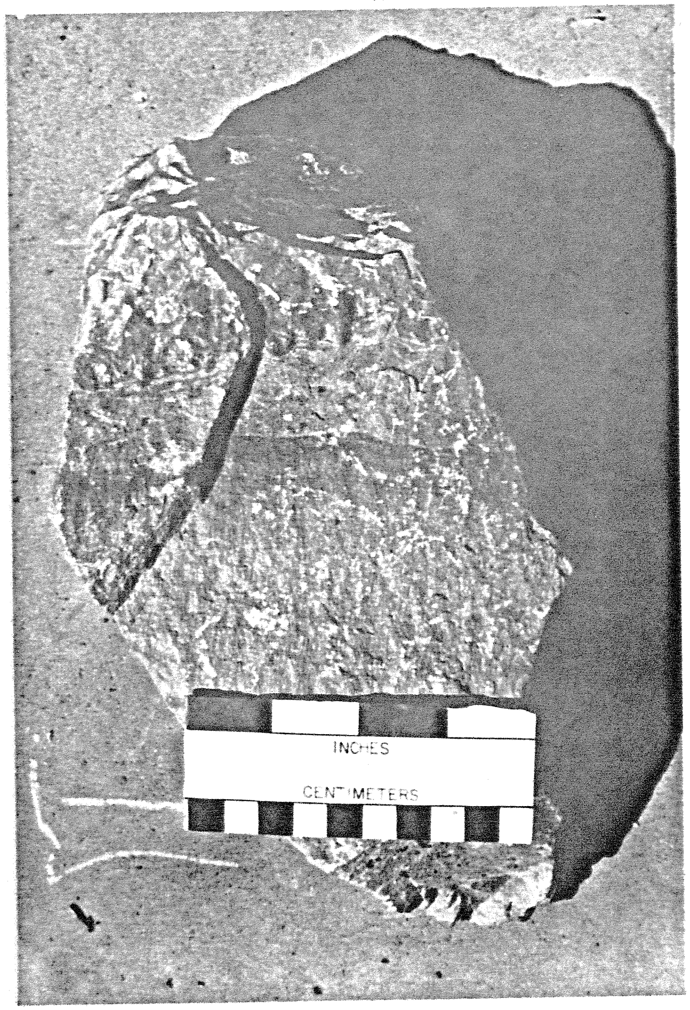


Figure 37

Banded quartzite and quartz-muscovite schist which shows good foliation. From section 9, T.28N. R.7E.

INTRUSIVE ROCKS

LINEATED GRANODIORITE (MAQUINITA GRANODIORITE)

Outcroping across the entire northern portion of the study area is a weakly to moderately foliated granodiorite which is gray to dark-gray, homogeneous, and moderately to strongly lineated (see Fig.38). The foliation and lineation are defined by the distribution and orientation of biotite knots. These knots are 1/2 to 2 cm long and are present even when foliation is weak.

The granodiorite is best exposed along the upper reaches of Maquinita Canyon, in sections 3, 4, and 5, T.28N. R.7E. It outcrops as massive, rounded to angular knolls and ridges and breaks with an uneaven surface or along foliation planes. It occurs as a pluton and as dikes and sills cutting the Moppin series and feldspathic metasediments. Contacts with the country rock parallel foliation and are both sharp and gradational. Xenoliths are common and range in size from a few centimeters up to 100's of meters (see Plate 1 Sec. 5 and 6, T28N R7E). The contact between the pluton and the greenschists is a "breccia zone" up to 150 meters wide of fragments of Moppin series rocks in a granodiorite matrix. Moppin series rocks near the granodiorite, either xenoliths or country rock have been altered by solutions from the granodiorite. Plagioclase and quartz seem to have been added.

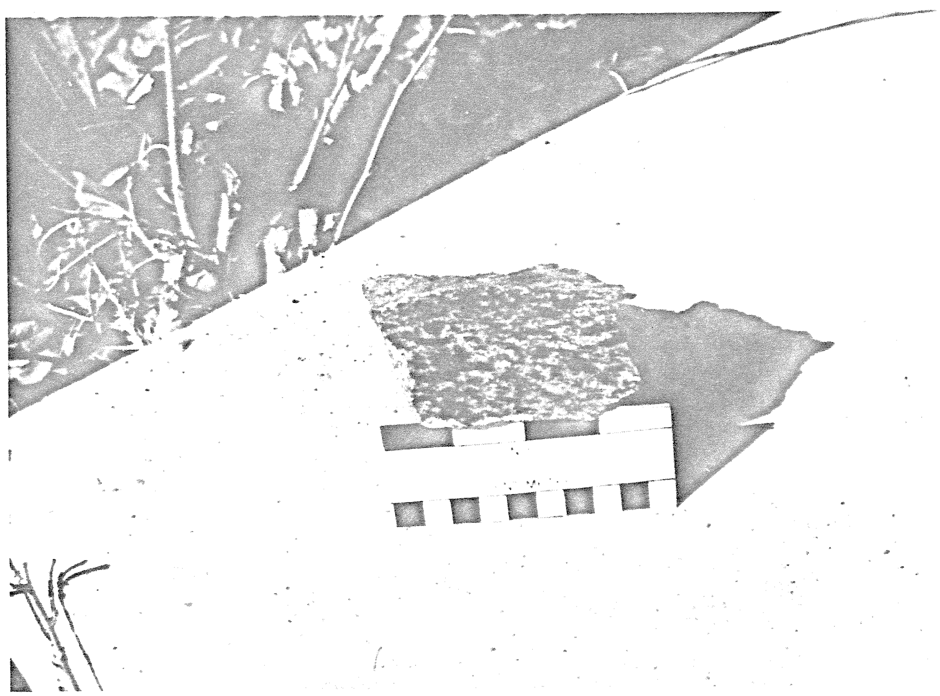


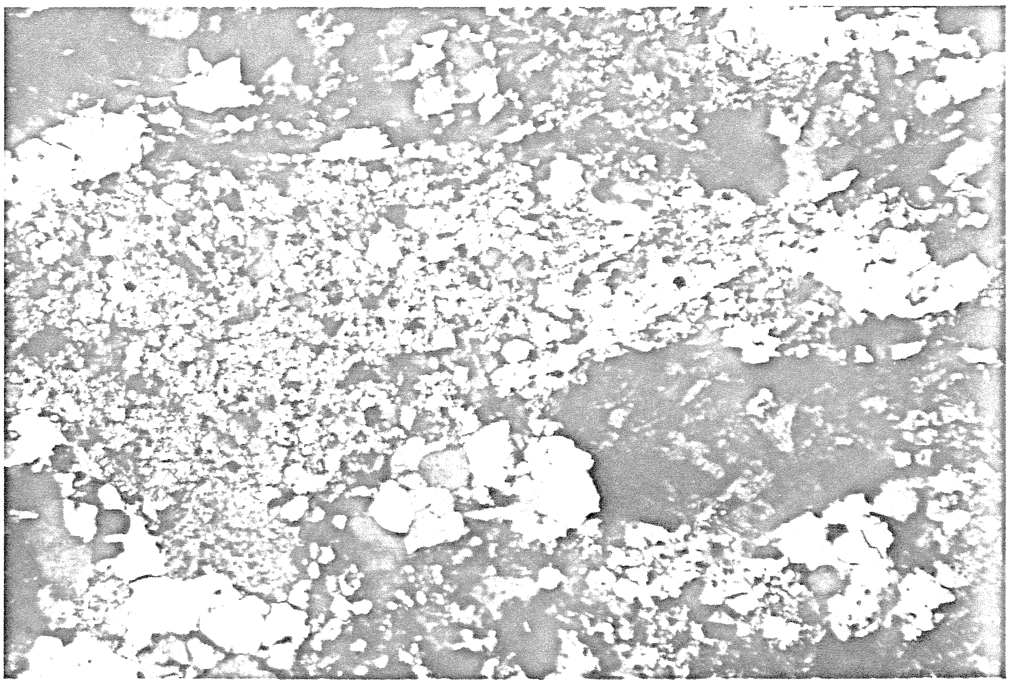
Figure 38

Lineated granodiorite (Maquinita granodiorite)
From Maquinita Canyon, section 4, T.28N. R.7E.

Thin section examination reveals the rock is composed of 50 to 60 percent plagioclase (albite-oligoclase) crystals 1 to 5 mm in length which have been slightly sericitized and ground against their neighbors. Quartz crystals 1 to 4 mm in diameter (often recrystallized into aggregates of smaller crystals) and small intergranular crystal make up 10 to 20 percent of the rock. Biotite comprises 5 to 15 percent of the rock, sericite 5 to 10 percent, and epidote, clinozoisite, and calcite are common in accessory amounts. The knots of biotite +/- chlorite are oriented in the same direction and often contain minor calcite and epidote. Fractures in the rock have been filled with muscovite and minor calcite (See Fig. 39).

GRANODIORITE OF SPRING CREEK

This rock was first described by Kent (1980) who separated it from the Maquinita granodiorite and is found in the eastern portions of the study area along Sheep Gulch and Rock Creek in sections 15 and 22, T28N R7E. Its outcrops poorly and is moderately to well foliated. It exhibits prominent rounded, blue quartz and plagioclase phenocrysts, and a reddish-pink color on weathered surfaces. It was differentiated from the Maquinita granodiorite by rarity of biotite knots, prominent quartz phenocrysts, and its reddish-orange color. It breaks along foliation planes exhibiting a pinkish-gray color on fresh surfaces and a finer grained matrix of quartz, muscovite, and chlorite.



5.0 mm

Figure 39

Photomicrograph of Lineated Granodiorite, from Maquinita Canyon, section 4, T.28N. R.7E. (10X and crossed Nicols).

Contacts were rarely observed in the field, but appeared to be similar to those of the Maquinita granodiorite and the Moppin series rocks.

Thin section examination reveals bent and broken, highly sericitized, albite-carlsbad twined, plagioclase phenocrysts comprise 35 to 45 percent of the rock. Rounded aggregates and fine grained matrix quartz made up 30 to 45 percent of the rock, muscovite (inc. sericite) makes up 10 to 15 percent, and biotite, chlorite, epidote, and magnetite are common accessory minerals. Hematite was seen in trace amounts. Cataclastic textures such as broken and bent plagioclase and strained quartz were common. Fractures were filled with muscovite and minor epidote.

GRANITE OF HOPEWELL LAKE (TRES PIEDRAS GRANITE)

The granite of Hopewell Lake is a medium grained porphyritic granite similar to the granite outcroping on the north side of Tusas Mountain, except for being better foliated an containing numerous inclusions. Bold rounded to angular outcrops can be found along Placer Creek and on a hill northeast of Hopewell Lake (See Fig. 40). The inclusions range in size from a few centimeters up to a few meters. These inclusions are largely mafic Moppin series rocks and very rarely feldspathic metasediments. It occurs as a small pluton and as dikes in the country rock. Contacts with the inclusions and the country rock are sharp.

This weakly foliated granite weathers pink, flesh-colored, or reddish- orange and has quartz and orthoclase crystals standing in relief.

Examination of samples in thin section reveal the plagioclase crystals to be albite-oligoclase (An 5 to 25), carlsbad-albite twined, sericitized, and often slightly embayed. Plagioclase makes up 20 to 30 percent of the rock, quartz 20 to 30 percent, orthoclase 20 to 25 percent, and muscovite 5 to 15 percent. Biotite, chlorite, and epidote are common as accessory minerals and hematite and magnetite are rare. Fractures are filled with muscovite +/- minor epidote and chlorite.

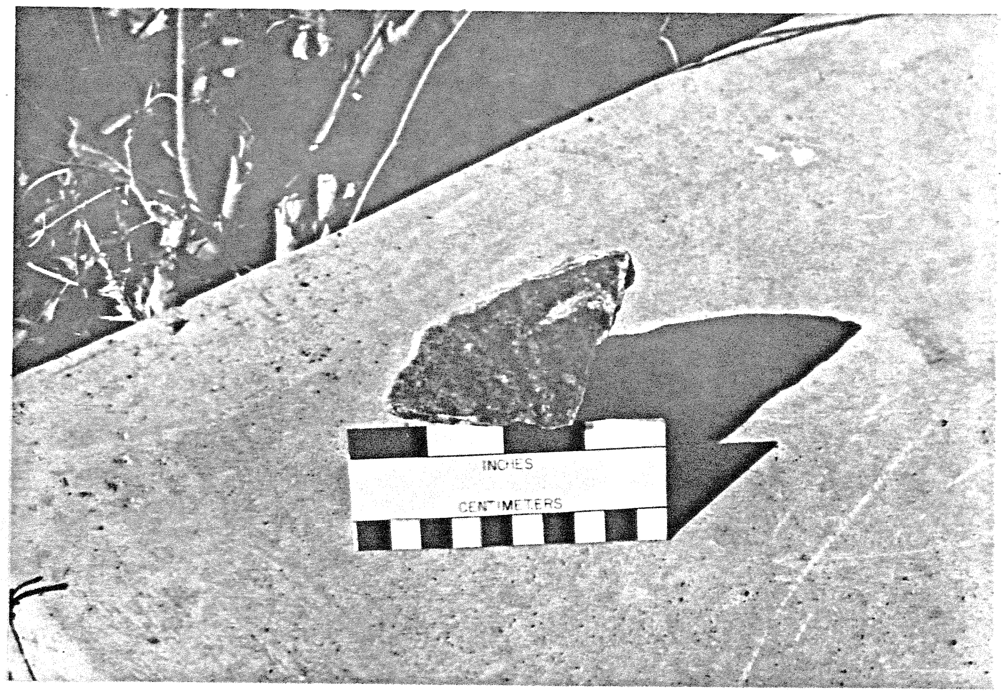


Figure 40

Granite of Hopewell Lake (Tusas Granite)
From east of Lake, section 32, T.29N. R.7E.

APPENDIX II

ROCK DESCRIPTIONS AND LOCATIONS

TG01 (NE 1/4 NE 1/4 SEC. 21, T.28N. R.7E.) Burned Mountain metarhyolite. Pink or reddish-gray, porphyritic, weakly foliated felsic schist; 50% quartz, 40% microcline, 10% muscovite +/- magnetite, hematite, and apatite; compares to Nockolds (1954) average rhyolite except enriched in potassium and depleted in sodium and iron.

TG02 (SE 1/4 SE 1/4 SEC. 16, T.28N. R.7E.) Porphyritic quartz-muscovite-chlorite schist. Well foliated green to greenish-gray porphyritic schist; 35% chlorite, 20% muscovite, 20% quartz, 10% fractured plagioclase megacrysts, +/- magnetite, calcite, epidote, hematite; compares to Nockolds (1954) average tholeiitic basalt except enriched in silica, alumina, sodium, and potassium and depleted in calcium and magnesium.

TG03 (NE 1/4 SE 1/4 SEC. 16, T.28N. R.7E.) Porphyritic quartz-calcite-chlorite schist. Well foliated green to greenish-gray porphyritic schist; 30% chlorite, 25% calcite, 20% quartz, 15% muscovite, 10% plagioclase, +/- magnetite, hematite, and epidote; compares to Nockolds (1954) average tholeiitic basalt except enriched in alumina, sodium, and potassium and depleted in calcium and magnesium.

TG04 (NW 1/4 NE 1/4 SEC. 16, T.28N. R.7E.) Metagabbro. Green to gray weakly foliated calcite-quartz-chlorite schist with remnant diabasic texture; 40% chlorite, 20% calcite, 20% quartz, 10% muscovite, 10% epidote/clinozoisite; compares to Nockolds (1954) average gabbro except enriched in alumina and sodium and depleted in silica and calcium.

TG05 (NW 1/4 NE 1/4 SEC. 16, T.28N. R.7E.) Porphyritic muscovite-quartz-chlorite schist. Weakly foliated, grayish-green, porphyritic schist; 40% chlorite, 20% quartz, 20% muscovite, 15% calcite, 5% plagioclase megacrysts, +/- epidote, magnetite; compares to Nockolds (1954) average tholeiitic basalt except enriched in alumina, sodium, and potassium and depleted in magnesium and calcium.

TG06 (NE 1/4 SE 1/4 SEC. 21, T.28N. R.7E.) Burned Mountain metarhyolite. Porphyritic, pink, weakly foliated felsic schist; 50% quartz, 35% microcline, 15% muscovite, +/- magnetite, hematite; compares to Nockolds (1954) average rhyolite except depleted in sodium and iron.

TG07 (NW 1/4 NW 1/4 SEC. 9, T.28N. R.7E.) Lineated granodiorite (Maquinita granodiorite) moderately foliated granodiorite; 35% plagioclase, 20% quartz, 15% biotite, 10% microcline, 10% chlorite, 5% epidote/clinozoisite; compares to Nockolds (1954) average granodiorite except enriched in alumina and sodium and depleted in calcium and potassium.

TG08 (SW 1/4 SE 1/4 SEC. 5, T.28N. R.7E.) Undivided Moppin schist near intrusive. Weakly foliated greenish-gray porphyritic calcite-quartz-chlorite schist; 30% chlorite, 25% quartz, 25% calcite, 20% plagioclase megacrysts, +/- epidote, magnetite; compared to Nockolds (1954) average tholeiitic basalt this rock is enriched in silica, alumina, and sodium and depleted in magnesium, calcium, and potassium.

TG09 (NE 1/4 SW 1/4 SEC. 32, T.29N. R.7E.) Granite of Hopewell Lake (Tusas granite) weakly foliated granite; 40% plagioclase, 30% quartz, 20 % potassium feldspar, +/- epidote, hematite, magnetite, biotite; compares to Nockolds (1954) average granite except enriched in alumina and sodium and depleted in potassium.

TG10 (SW 1/4 SEC. 33, T.29N. R.7E.) Lineated granodiorite (Maquinita granodiorite) moderately foliated granodiorite; 30% quartz, 30% plagioclase, 20% biotite, 10% microcline, 5% muscovite, +/- magnetite; compares to Nockolds (1954) average granodiorite except enriched in sodium and depleted in calcium and potassium.

The intrusive rock's petrographic classifications were done using estimated modal percentages and Streckeisen classification (1973).