GEOLOGY OF THE WATER CANYON AREA, MAGDALENA MOUNTAINS SOCORRO COUNTY, NEW MEXICO.

by

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ABSTRACT

The Water Canyon area is in the east-central portion of the Magdalena Mountains, Socorro County, New Mexico about 16 miles west of Socorro and 12 miles southeast of Magdalena.

The Magdalena Mountains are a short north-south trending, westward tilted, block faulted mountain range typical of mountains found in the Basin and Range province. The Water Canyon area represents a portion of the main range about 4 miles long and 2 to 4 miles in width into which Water Canyon has been incised.

Westward tilted Carboniferous sediments lie unconformably on a basement of Precambrian greenstone and granite and are overlain by and faulted against a 4000 foot sequence of Tertiary tuffs, lavas, and agglomerates varying in composition from rhyolite to andesite.

The area is bounded on the east by a northwest trending normal fault zone which defines the entire eastern face of the Magdalena Range. Vertical and near vertical faults with throws as great as 6000 feet evidence the adjustment of fault blocks to tensional forces which are presumed to have resulted from the weakening of the basement following removal of large amounts of molten rock during the period of Tertiary volcanic activity. The faulting, which was initiated in Laramide time appears to have continued to the present.

INTRODUCTION

Location and Accessibility

The Water Canyon area is situated in the north-south trending Magdalena Mountains of Socorro County, New Mexico 16 miles west of Socorro and 12 miles southeast of Magdalena (fig. 1). It lies within the boundaries of the Magdalena Division of the Cibola National Forest.

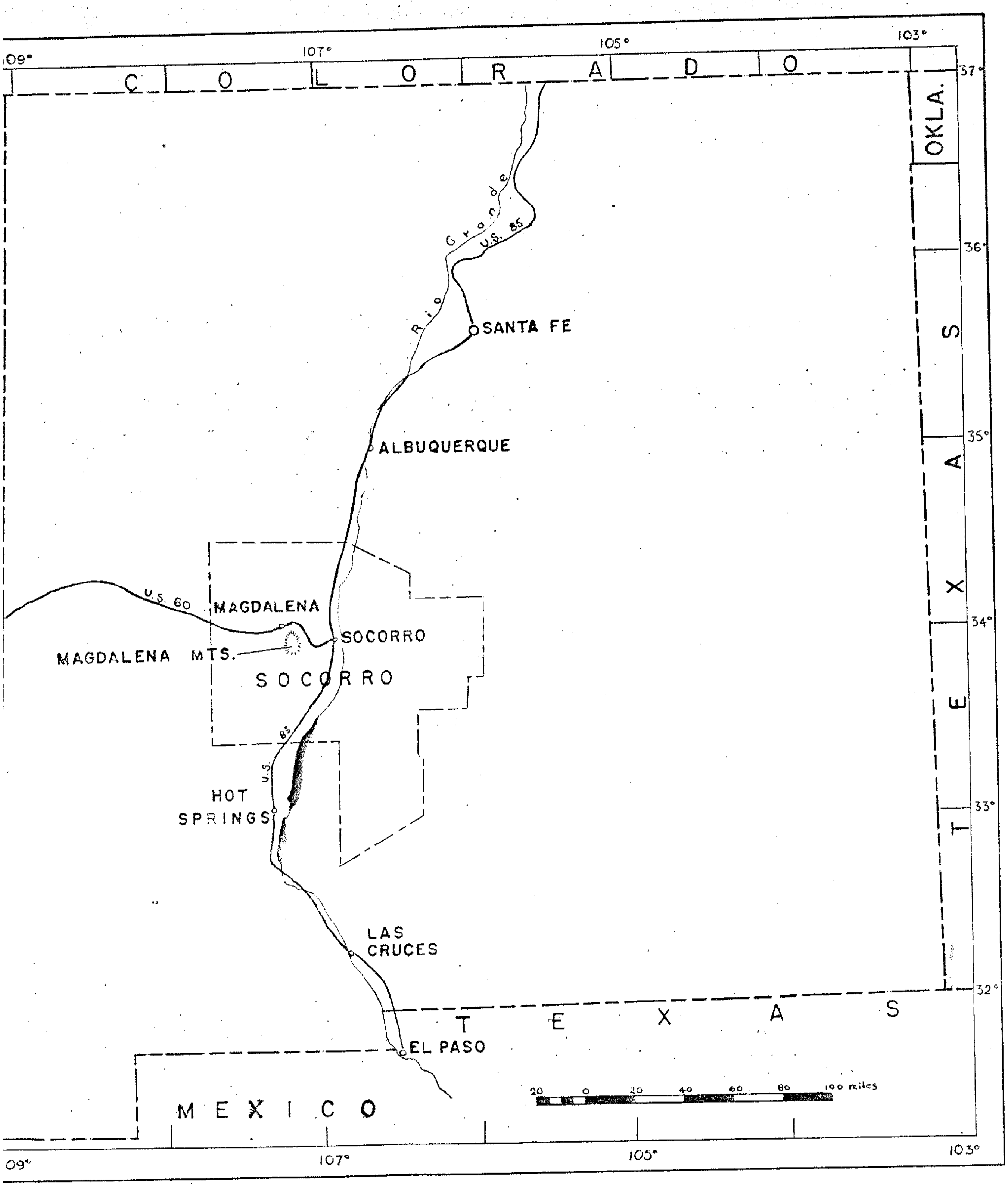
The area is accessible via U.S. Highway 60, a hard surfaced all weather road which leaves U.S. Highway 85 at Socorro and extends westward to Arizona via Magdalena and Datil, New Mexico. The Water Canyon road which joins U.S. Highway 60 about 16 miles west of Socorro is a graded dirt road maintained by the U.S. Forest Service. It cuts through the northern and western part of the mapped area and constitutes the only access road in this area. A poor, often impassable dirt road joins U.S. Highway 60 four miles south of the Water Canyon turnoff and leads to the mouth of South Canyon. Although several mine roads join the Water Canyon road only the one serving the Buckeye Mine in Copper Canyon was accessible by car during the time the area was mapped.

The region is served by the Magdalena branch of the Atchison, Topeka and Santa Fe railroad with a siding at Water Canyon. The Magdalena branch joins the Albuquerque-El Paso main line at Socorro. During the active days of the Magdalena Mining District, the town of Magdalena served as the main shipping point for ore in the region and it still holds some importance as a shipping point for cattle from an extensive grazing country to the west.

Purpose and Scope

The purpose of the geologic investigation of the Water Canyon area

Fig. 1



Index map of New Mexico showing location of Magdalena Mountains.

is three-fold: 1) to study the hitherto undifferentiated volcanic rocks east of the Water Canyon fault; 2) to determine what relationship, if any, the Tertiary volcanic rocks in the area bear to those in the Magdalena Mining District; 3) to investigate the structural features of the area and their relationship to those in other parts of the Magdalena Range.

The investigation was begun in August 1951 and carried on intermittently from that time until the first week of June 1952. In all 98 days were spent in the field during which time approximately ten square miles were mapped. The area covered by the investigation includes portions of secs. 30 and 31, T3S, R2W and portions of secs. 13, 14, 22-27, 34-36, T3S, R3W, New Mexico Base and Meridian.

Data obtained in the field were plotted on vertical air photographs taken for the Soil Conservation Service. The photographs were of rather poor quality and large variations in scale between adjacent flight lines coupled with the complete absence of a flight line covering the area immediately west of Water Canyon sharply curtailed stereoscopic coverage. Information on the air photographs was transferred to an unpublished, partially completed (due to absence of flight lines) planimetric map compiled by the Soil Conservation Service in Albuquerque, New Mexico.

Dips and strikes were taken with a Brunton compass while thicknesses of units were obtained by pacing, aneroid barometer, and Brunton compass used as a hand level. No bench marks are present in the mapped area and elevations used in plotting cross sections were obtained by correcting aneroid barometer readings for diurnal variation. The barometer was read at the bench mark at the School of Mines in Socorro at the beginning and end of each field day.

Topography and Drainage

Elevations in the general region range from about 6000 feet at the junction of Water Canyon road and U.S. Highway 60 to about 10,800 feet atop South Baldy two miles west-southwest of the southwestern corner of the mapped area. Topographic relief in the mapped area is about 1300 feet and vertical to near vertical cliffs and canyon walls bound the volcanic area between Water Canyon and South Canyon.

There are no perennial streams in the area mapped, but Water Canyon and South Canyon, both of which head on South Baldy, carry off excess rainfall and melted snows which are not absorbed by the alluvium. North Fork Canyon and Copper Canyon, both of which are tributary to Water Canyon, drain the area south of North Baldy several miles northwest of the mapped area. Several of the streams in the area, notably Water Canyon, are fault or joint controlled in part at least. A shallow groundwater circulation feeding several wells and a few springs is maintained throughout the year.

Vegetation

Cholla and prickly pear cactus and Spanish bayonet characteristic of the Upper Sonoran biologic environment, are found on the gravel plain east of the Magdalena Mountain front and also on the lower slopes of the canyon walls in Water Canyon and South Canyon. Higher slopes are characterized by the presence of mock rose and scrub oak. Ponderosa pine is by far the most common tree in the area with juniper, spruce, aspen and a few cottonwood trees also present. A few Douglas fir (?) are present in the southernmost portion of the area.

Climate

The climate of the region is mild with extremes in temperature occurring only during short periods of the winter and summer. The rainy season extends through July and August and during this time some precipitation can be expected during the early afternoons. However, during the course of the field work rainfall did not exceed half an hour in duration and none was heavy enough to delay work more than a few minutes. Snows, however, did curtail field work rather seriously from late December 1951 to February 1952.

Previous Work

Little geologic work has been done in the Water Canyon area. Gordon (1910) reported on the geology and ore deposits of the Magdal-ena District and included a short note on mining in the Water Canyon area. He recognized the presence of "greenstone schists" in the area. Wells (1918) reported on the occurrence of manganese in red rhyolite on the east side of Water Canyon. Lasky (1932) described a few of the ore occurrences in several of the tributaries of Water Canyon. The Empire Zinc Company carried out an exploration program in 1949 to determine the presence of commercial base metal mineralization in the Kelly limestone, however their findings have not been published. Smith (1951) assisted by the author mapped a small area surrounding the Buckeye Mine in Copper Canyon.

Acknowledgments

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GEOLOGY

Precambrian Rocks

The oldest rocks in the region are greenstone and granite of pre-Mississippian age. Loughlin and Koschmann (1942) have assumed them to be Precambrian on the basis of their structural similarity to Precambrian rocks elsewhere in the state. Their assumption appears to be well founded and the rocks in question have been dated as Precambrian in this paper.

GREENSTONE: The rocks mapped as greenstone were first described by Gordon (1910) as "greenstone schists". He recognized their occurrence in the Water Canyon area. Loughlin and Koschmann (1942) mapped the unit as "argillite" and included in this unit both argillite and greenstone. In the Water Canyon area the unit in general exhibits an incipient schistosity and locally it is fairly well defined. In most occurrences, however, such structure can be identified only by microscopic study. The rock is best exposed in sections 22, 23, 26 and 27 on the west side of Water Canyon. On the north it is in intrusive contact with the Precambrian granite while on the south it appears to be in unconformable contact with Carboniferous sediments. Its eastern boundary is, for the most part, obscured by alluvium but undoubtedly extends some short distance eastward to be cut sharply by the Water Canyon fault.

The greenstone is light gray-green to dark green in color and weathers to buff or gray. Locally, as near the mouth of Copper Canyon, it exhibits a distinctive blocky type of weathering which has been produced by the intersection of three separate joint systems. Only one exposure of the color banding reported by Loughlin and Koschmann (1942) was noted in the mapped area. This occurrence is in Water Canyon immediately south of the mouth of Copper Canyon. The bands range in thickness from less than 1/8 inch to 3 or 4 inches and appear to be nearly parallel to the north-south strike of the unit. A metamorphosed pebble conglomerate (?) is exposed several hundred yards west of the junction of Water Canyon and Copper Canyon and also in North Fork Canyon. Light gray to green or brown particles from 1/8 to 1/4 inch in length, oval to circular in plan, and lenticular in cross section are scattered abundantly through the greenstone. The long axes are closely parallel within small areas though the orientation of the alignment is different in various outcrops. In hand specimen no definite mineral grains can be identified but the rock has a distinctly siliceous appearance.

Microscopic study revealed the presence of quartz, chlorite, and muscovite and minor amounts of magnetite. The quartz generally occurs in angular fragments which show no strain and which are uniformly .04 mm. in diameter. It forms from 20 to 25% of the rock and is imbedded in a groundmass of fine chlorite and sericite flakes.

Irregular magnetite grains from .01 to .02 mm. in diameter are scattered throughout the section. A few sparse grains of orthoclase (?) are seen in some sections and oriented chlorite and sericite flakes occur in the more schistose varieties.

The unit is probably from 700 to 900 feet thick in the Water Canyon area while farther to the north Loughlin and Koschmann (1942) estimate a thickness of 2000 feet.

Color banding, differences in schistosity, and locally conglomerate-like nature indicate that the greenstone is the metamorphic product of what were probably sediments and perhaps locally tuffs and lavas.

GRANITE: Rock mapped as Precambrian granite is exposed in the northwesternmost part of the area where it is in fairly regular intrusive contact with the greenstone. It forms the face of the Magdalena Range from the mouth of Water Canyon up to the northern end of the mountain front. Well developed joint systems and a slight amount of biotite cause the granite to weather into angular blocks with rounded edges.

The granite while generally fine grained and pink throughout the Magdalena Range (Loughlin and Koschmann, 1942 and Gordon 1910) is coarse grained in the mapped area, some crystals reaching 3 to 4 mm. in length. It is generally stained buff though along the eastern edge of the range it is fine grained and assumes its more normal pink color. In most outcrops mapped the granite consists of coarse grains of pink to gray orthoclase and microcline and colorless quartz with a little biotite. Microscopically the granite consists of coarse grains of anhedral to subhedral orthoclase with a little microcline and perthite ranging in size from 2 to 6 mm. and quartz occurs both as coarse, strained, and fractured anhedral grains and as mosaic-like interstitial grains whose average size is about 1 mm. The latter type makes up about 15% of the rock. The coarser quartz grains contain numerous liquid inclusions. There is a small amount of biotite either partly or wholly altered to chlorite and minor amounts of magnetite. Generally the feldspars are thoroughly sericitized but a few fresh grains are present.

Carboniferous Sediments

The Carboniferous sediments include the Kelly limestone of Mississippian age and the Sandia formation and Madera limestone of Pennsylvanian age. These formations were mapped together for a number of reasons: 1) The poor quality of the aerial photographic coverage and the lack of stereoscopic coverage in the outcrop areas west of Water Canyon made accurate mapping difficult; 2) the complex nature and close spacing of the fault systems resulted in outcrops too small to show on the scale of the photographs and at times too small for the scale of the final map; 3) key horizons which might allow sharp distinctions between intraformational units were lacking in much of the section. In scattered areas the formations are clearly recognizable and the following descriptions are based on such outcrops.

KELLY LIMESTONE: The Kelly limestone was originally named the Graphic-Kelly limestone by Herrick (1904) and renamed the Kelly limestone by Gordon (1907) after the town of Kelly, New Mexico. Loughlin and Koschmann (1942) report a thickness of 90 to 135 feet in the Magdalena District but the maximum thickness found in the Water Canyon area is in the Buckeye Mine near the junction of Copper Canyon and Water Canyon where approximately 65 feet are exposed. This probably does not represent a true thickness since bedding plane faults may either exaggerate or reduce the thickness greatly. The Kelly limestone lies on the eroded surface of the greenstone or has been faulted against it.

The Kelly limestone is fine grained and generally gray to bluish gray in color. It has been much silicified and locally recrystallized. The gray dolomitic and slightly argillaceous horizon known as the "silver pipe" is prominent in the Magdalena district but could not be recognized in the Water Canyon area. The Kelly limestone has generally served as the host rock for base metal mineralization in the region and this holds true for the Water Canyon area though no mineralization approaching the scale developed in the Magdalena district has been found here.

The name "Magdalena Group" was first used by Gordon (1907) to describe the Pennsylvanian rocks in the Magdalena Mountains. While usage varies somewhat it is generally used synonymously with the Pennsylvanian system in New Mexico. Loughlin and Koschmann (1942) report an average thickness of 850 feet in the Magdalena district but only 750 feet are exposed in the Water Canyon area.

SANDIA FORMATION: The Sandia formation was first described by Herrick (1900) from exposures of shale, limestone and sandstone in the Sandia Mountains of Bernalillo County, New Mexico where it forms the lower half of the Magdalena Group.

The formation is poorly exposed in the Water Canyon area where it lies with apparent conformity upon the Kelly limestone. It is composed primarily of dark gray to black, fissile shales with thin interbedded limestone and quartzite members. The shale is highly fractured and generally bleached or stained. Loughlin and Koschmann (1942) divide the Sandia formation into a lower quartzite member, a lower limestone member, a middle quartzite member, a shale member, an upper limestone member and an upper quartzite member. These units are not recognizable in all areas where the Sandia formation is exposed and only the shale and upper limestone member are recognizable in the Water Canyon area. While Loughlin and Koschmann (1942) report the formation to be 600 feet thick in the Magdalena district only 200 feet is exposed in the Water Canyon area. The formation becomes more calcareous toward the top and grades upward into the overlying Madera limestone.

MADERA LIMESTONE: The Madera limestone was first named by Herrick (1899) after the town of La Madera, New Mexico on the east slope of the Sandia Mountains. It was used by Keyes (1905) to describe the upper part of the limestone beds in the Sandia Mountains and Gordon (1907) applied the name to the limestone beds overlying the Sandia formation in Socorro and Bernalillo Counties.

The Madera limestone forms the large majority of the outcrop area of the Carboniferous sediments. It lies conformably upon the Sandia formation from which it is separated by gradually increasing amounts of limestone and decreasing amounts of shale. The exact line of contact is somewhat arbitrary and any one of several 3 to 7 feet thick lenticular quartzite conglomerate beds might be considered a good contact as would the first massive limestone bed above the zone of quartzite conglomerate beds.

The Madera limestone is generally a medium to massive bedded, bluish gray, dense, fine grained limestone with interbedded thin shaly limestone members. In the mapped area it characteristically contains irregular streaks and masses of yellow to gray chert which have been brought out in sharp relief by differential weathering. Two thin quartzite conglomerate layers occur near the bottom of the formation and this along with the thinner bedded nature of the limestone at this horizon are indicative of the gradation between the Madera limestone and the underlying Sandia formation. The total thickness of Madera limestone is not exposed in the Water Canyon area as it is in the Magdalena district although a minumum thickness of 550 feet was measured in the northern part of section 34 west of Water Canyon. An apparent thickness of over 1800 feet is exposed in North Fork Canyon immediately west of the mapped area but this has undoubtedly been exaggerated by faulting.

While the Abo sandstone of Permian age is present in parts of the Magdalena district (Loughlin and Koschmann 1942) erosion has removed it completely from the Water Canyon area. However, the red stained limestone beds forming the upper part of the Madera limestone have probably been colored by material derived from the Abo sandstone as they have been in the Magdalena district (Loughlin and Koschmann 1942).

The Madera limestone is overlain with pronounced angular unconformity in the Water Canyon area by purple andesite, the oldest of the effusive igneous rocks in the area.

Tertiary Effusive Rocks

Lying upon the Paleozoic sediments and Precambrian greenstone and granite with sharp angular unconformity is a series of Tertiary effusive rocks which range in composition from rhyolite to andesite and attains a thickness in the Water Canyon area of about 4000 feet. The series includes tuffs, flows, and agglomerates which have, in part at least, been correlated with the volcanic sequence described by Loughlin and Koschmann (1942) in the Magdalena district. (fig. 3)

No compositional pattern of extrusive activity was noted in the sequence of volcanic rocks. However, without full knowledge of the centers of volcanic activity the existence of such a pattern cannot be completely discounted.

Loughlin and Koschmann (1942) have recognized two distinct periods of volcanic activity in the Magdalena district which were separated by a period of faulting and erosion. The lower series is absent or buried beneath younger rocks in the Water Canyon area and the volcanic rocks exposed here are the equivalent of Loughlin and Koschmann's late series of volcanics. Tuffs are rather common in the volcanic area to the north but only two tuff units, one in the purple andesite and the other in the streaked rhyolite, have been found in the mapped area. The progressive decrease of tuff in the younger volcanic units suggests that the onset of volcanic activity was rather violent and grew progressively calmer.

The volcanic units are exposed east of Water Canyon where they represent a downthrown fault block which is now in contact with Pre-cambrian, Carboniferous, and early Tertiary rocks exposed on the west side of the Water Canyon fault.

The rocks have been named after the colors and textures which characterize their appearance either in the field or in thin section.

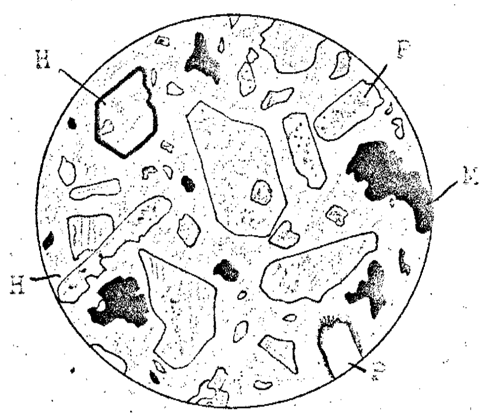
PURPLE ANDESITE: The purple andesite forms the basal volcanic unit in the Water Canyon area where it lies unconformably upon upper beds of Madera limestone. Loughlin and Koschmann (1942) report that in various localities in the Magdalena district it lies upon Abo sand-stone, Madera limestone or Sandia formation thus further pointing up the unconformable nature of the Tertiary volcanic rocks. The purple andesite is best exposed in the southwest corner of the mapped area where it is in fault contact with rhyolite porphyry. Two interpretations of the contact relationships are possible. First, the purple andesite and the rhyolite porphyry may have been brought together by movement along the Water Canyon fault, or second, the rhyolite porphyry may have been intruded along the fault in which case the contact is in part intrusive. Evidence is lacking to clearly substantiate either altern-ative, but due to the lack of observable contact effects which would probably attend such an intrusion the first alternative is favored. A small outcrop of purple andesite occurring on the east wall of Water Canyon in section 26 has been faulted against the younger streak-ed rhyolite. Since it is not overlain by any volcanic units in the mapped area and since also its contacts with other Tertiary volcanic

Purple Andesite. Plagioclase (P) and hornblende show sericitization and replacement by calcite

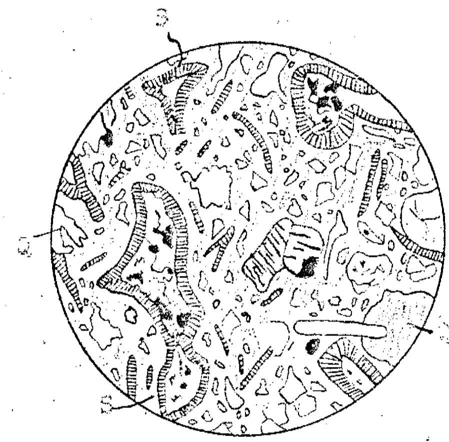
Streaked rhyolite. Tuff member show crystals shells (S) filled with mosaic quartz (Q).

Streaked rhyolite. Hand speciman showing lenticular streakes in fine grained groundmass with phenocrysts of quarts (Q) and feldspar (F)

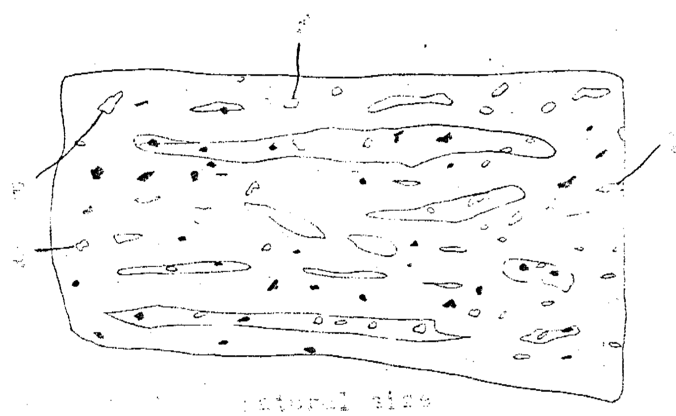
PLATE I



x 20
crossed nicols



x 60
crossed nicols



natural size
plain light

units is always a fault contact the exact position of the purple andesite in the volcanic sequence is not known though its position above the Madera limestone suggests that it is the oldest of the exposed volcanic units. Such an argument, however, loses much of its force if the possibility of two or more centers of eruption is taken into account.

The purple andesite is composed exclusively of flow units in the mapped area though a short distance to the west it contains some coarse breccia. Fragments of red siltstone, undoubtedly derived from the Abo sandstone, are scattered throughout the lower portions of the flow. The portions of the unit exposed in the Water Canyon area are probably correlative with the flow units at the top of the purple andesite found farther to the north. The formation has an estimated thickness of 800 feet.

Thin sections show phenocrysts of plagioclase feldspars, hornblende, magnetite and a few quartz grains imbedded in a microcrystalline groundmass. Phenocrysts form 40% of the rock. The feldspars have been almost completely sericitized and in part replaced by calcite thus making positive identification of the plagioclase impossible. A ferromagnesian mineral with outlines suggesting hornblende constitutes about 5% of the phenocrysts. It has been altered to brownish chlorite and iron oxide. A few grains of magnetite, some as large as 0.5 mm. are scattered throughout the section and locally some small aggregates of secondary quartz are present. The groundmass while generally microcrystalline is locally spherulitic and suggests that the alteration of the rock resulted in some devitrification of the groundmass (Tyrell, 1929)

EARLY RED RHYOLITE: The early red rhyolite is best exposed in the southeast corner of the mapped area where it forms the steep slopes at the mouth of South Canyon. It is overlain by, and at times in fault contact with, the streaked rhyolite and, on the east face of the range north of the mouth of South Canyon, the early trachytic andesite. The lower contact of the early red rhyolite has not been found and the true thickness of the unit is not known though it has a minimum thickness of 400 feet. The rock is characteristically red-brown in color and exhibits a porphyritic texture with scattered phenocrysts of glassy quartz up to 2 mm. in diameter and a few small feldspar laths and biotite flakes in a red siliceous matrix.

In thin section phenocrysts form about 40% of the rock. Anhedral quartz grains about 0.75 mm. in diameter constitute about 30% of the phenocrysts. The quartz is light gray to yellow in color and is unstrained and very little fractured. Subhedral orthoclase ranges in size up to 1 mm. with about 0.5 mm. representing the average size. The orthoclase crystals are usually corroded and some have been replaced by calcite. Brown to green pleochroic hornblende with tabular outlines are about 0.4 mm. long and constitute about 10% of the phenocrysts. Some fine grained apatite and magnetite occur as accessory minerals in minor amounts throughout the section. The red-brown microcrystalline groundmass locally has a hint of flow banding.

EARLY TRACHYTIC ANDESITE: The early trachytic andesite outcrops in a thin curving band on the east slopes of the range and the north wall of South Canyon in sections 30 and 31. Although the unit weathers rapidly and its lower contact is not visible owing to a cover of talus material, its attitude indicates that it overlies the early red rhyolite.conformably. Its maximum thickness is 50 feet. Its general thinness, absence south of South canyon and thinning to the north along with its very even upper contact suggest a minor erosional unconformity between it and the overlying streaked rhyolite. The early trachytic andesite is a vesicular, deep red to brown andesite resembling dense hematite. No phenocrysts are observable in hand speciman. Some of the vesicles are lined with calcite.

In thin section the early trachytic andesite consists of parallel to sub-parallel andesine laths averaging 0.15 mm. to 0.2 mm. in length in a glassy, vesicular, deeply iron stained groundmass. A few magnetite grains are scattered throughout the groundmass and are altered to hematite about their peripheries. The vesicles average 3 to 4 mm. in length and some as large as 7 mm. have been noted in hand speciman.

STREAKED RHYOLITE: The streaked rhyolite lies with minor erosional unconformity on the early red rhyolite and early trachytic andesite in the southeast corner of the mapped area. Farther to the north along the front of the range and in the northern part of Water Canyon its lower contact is obscured by alluvium. To the south in section 35 it is in fault contact with the rhyolite porphyry. A rather pronounced erosional unconformity at its upper contact is indicated by the fact that it is locally overlain by either the pink rhyolite, rhyolite agglomerate or late trachytic andesite. Both in areal extent and thickness it is the most important unit in the Water Canyon area and has been correlated with what Loughlin and Koschmann (1942) have termed the "banded rhyolite" in the Magdalena district. The formation consists of three members, a lower tuff, a flow-banded middle member and an upper streaked member. Its total thickness is about 1300 feet.

The lower tuffaceous member is best exposed in South Canyon about a mile west of the canyon's mouth where a thickness of about 500 feet was measured. It is characteristically pinkish gray in color and in hand specimen consists of an extremely fine grained siliceous matrix with a few scattered phenocrysts of orthoclase and occasionally smoky quartz. It is also characterized by the presence of gray to black irregular streaks about 1 inch in length which have a scoriaceous appearance. Small xenoliths of older rocks are present locally and have usually been so altered in appearance as to make identification impossible. However, near the lower contact of the tuff, xenoliths consisting of fragments of early trachytic andesite have been recognized. This further strengthens the idea of an erosional unconformity at the base of the streaked rhyolite.

The middle banded member is present locally in Water Canyon and on the east face of the range south of Water Canyon in section 25. The rock is fine grained to aphanitic, consisting of alternating gray, pink and reddish brown bands varying in thickness from 1/32 to 1/4 inch and exhibiting excellent jointing parallel to the plane of flow banding. In the exposure on the east face of the range the bands are vertical and remarkably straight. The outcrop on the east wall of Water Canyon in section 26 exhibits much contortion and fracturing and the fractures are filled with a siliceous red material similar in appearance to the matrix of the rhyolite agglomerate. It is 200 feet thick.

The streaked upper member is the thickest and areally most extensive of the three members. It thickens appreciably, as does the tuff member, toward the southwest and this suggests that the source of the tuff member and streaked upper member was somewhere in the vicinity of South Baldy about 2 miles west-southwest of the southwest corner of the mapped area. The streaked member is best exposed in South Canyon in section 36 where it reaches its maximum thickness of about 600 feet. A normally reddish brown, porphyritic matrix contains pink to buff streaks which are lenticular in cross section and oval in plan. The streaks attain a length of 3 inches and thickness of 3/4 of an inch though they average about 1 inch in length and 1/4 inch in thickness. The streaks are very fine grained and are themselves porphyritic containing phenocrysts of glassy clear quartz and orthoclase as does the matrix of the rock.

In thin section the streaked rhyolite is variable. The tuff member consists of fine glass shards which make up about 70% of the rock. They range in size from 0.08mm. to 0.1 mm. in length. A few scattered anhedral orthoclase phenocrysts about 0.5 mm. in size and at times ranging up to 2 mm. are generally sericitized about their peripheries. Shells or the remains of early formed phenocrysts commonly softened and distorted, possibly by a rise in temperature at the time of eruption, are scattered throughout the section and have been filled with secondary mosaic quartz. Occasionally only fragments of such shells are found suggesting that crystals may have been nearly destroyed by the violence of the eruption.

Microscopic study reveals little about the middle banded member not seen in hand speciman. The rock is strongly banded and glassy and in several places thin streaks of fine grained secondary mosaic quartz have been deposited along the contacts between bands suggesting that such contacts served as good passageways for siliceous solutions. A few anhedral quartz phenocrysts are scattered throughout the rock and attain a maximum size of 0.2 mm.

The upper streaked rhyolite member exhibits a porphyritic texture in thin section, with phenocrysts constituting about 20% of the rock. These range in size from 0.8 mm. to 2 mm. but the average size is about 1 mm.; they consist of orthoclase and quartz with some scattered biotite and magnetite. Crystals are subhedral but partial resorption obscures their outlines to varying degrees. Much of the orthoclase has been attacked and altered along cleavage planes. The groundmass is glassy and unequal distribution of iron oxide stain lends a faint banded appearance to the rock in plain light. Locally the groundmass exhibits radial or spherulitic growths which, where complete, are seen to have crystallized about minute quartz (?) grains. These may represent partial devitrification of the glassy groundmass under the influence of hot deuteric solutions or, as has been suggested by Loughlin and Koschmann (1942), an intergrowth of potash feldspar and cristobalite. The fine grained lenticular streaks seen in hand speciman are zones of fine grained secondary mosaic quartz which often contain subhedral corroded orthoclase crystals. The streaks probably represent vesicles which have been filled with quartz and orthoclase deposited from deuteric solutions.

LATE TRACHYTIC ANDESITE: Overlying the streaked rhyolite and separated from it by a minor erosional unconformity is a red trachytic andesite which closely resembles the early trachytic andesite. The unit outcrops on a spur on the east face of the range in section 24 and forms the cap rock at the top of the east facing cliffs in section 25. It is ordinarily overlain by the rhyolite agglomerate but in the latter occurrence it is faulted against the agglomerate and andesite porphyry. In section 26 it outcrops on the west facing cliffs of Water Canyon and is overlain unconformably by the pink rhyolite. Several small outcrops occur in sections 23 and 26 on the east wall of Water Canyon. The maximum thickness of the unit is 175 feet but it is ordinarily somewhat thinner.

Like the early trachytic andesite the late trachytic andesite is deep red-brown in color and exhibits some vesicular structure though vesicles are restricted to the top 10 to 15 feet of the unit. The groundmass is extremely fine grained and contains scattered grains of quartz which reach a diameter of 1 mm. and which, the microscope reveals, are secondary in origin. Locally the lower 2 to 3 feet contain angular fragments of the underlying streaked rhyolite which suggests a minor erosional interval preceeding the deposition of the late trachytic andesite.

The andesite is porphyritic in thin section with phenocrysts of potash feldspar in a fine grained groundmass of aligned feldspar laths and microlites. The average length of the laths is about 0.07 mm.

and they are too small and poorly developed to determine their exact composition. Their outlines, however, suggest plagioclase laths. A few thinly scattered orthoclase phenocrysts are present. These range in size from about 0.07 mm. to 0.1 mm. and characteristically exhibit corroded centers. About 5% of the rock is composed of magnetite grains which average about 0.25 mm. in diameter but a few reach 0.5 mm. They are altered to hematite about their peripheries and this imparts much of the red color to the rock. Scattered clusters of secondary mosaic quartz are present but there is no primary quartz unless it is occult in the groundmass.

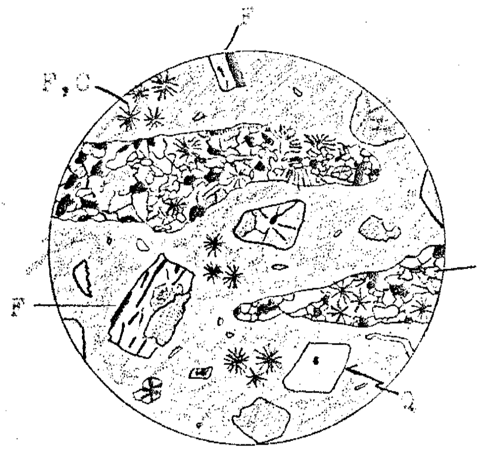
RHYOLITE AGGLOMERATE: The rhyolite agglomerate is the most prominent and distinctive of the Tertiary volcanic units outcropping in the area. It forms the east wall of Water Canyon for more than a mile south of the canyon's mouth and the east facing cliffs of the Magdalena Range for about a mile south of the mouth of Water Canyon. It also outcrops at the top of the cliffs north of the mouth of South Canyon. The unit ordinarily rests upon the late trachytic andesite though where, due to erosion or non-deposition, the late trachytic andesite is not present it rests on the streaked rhyolite as in sections 25 and 30. It is normally overlain by the andesite porphyry though in section 26 where the andesite porphyry has been removed it is overlain by the late red rhyolite. It also is in fault contact with some of the younger volcanic units as in the southwest 1/4 of section 26 and the west 1/2 of section 25. It has a maximum thickness of 500 feet and exhibits no great variation in thickness except where erosion has obviously removed portions of it.

A. Streaked rhyolite. Lenticular streaks filled with mosaic quartz (Q) and spherulites of feldspar (F) and cristobalite (C).

B. Late trachytic andesite. Aligned feldspars (F) and microlites with scattered magnetite (M) grains partly altered to hematite (H).

C. Rhyolite agglomerate. Rounded rock fragments in clear quartz (Q) in a red glassy groundmass.

D. Andesite porphyry. Zoned plagioclase (F) and hornblende (H) with euhedral magnetite (M) and apatite (A).



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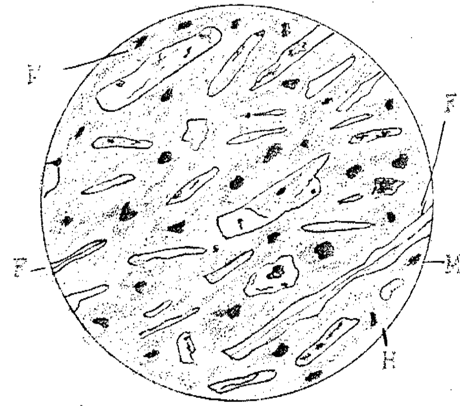

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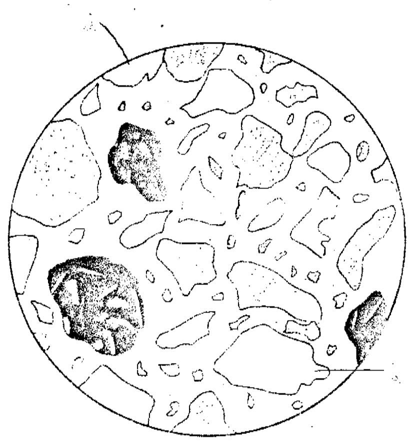

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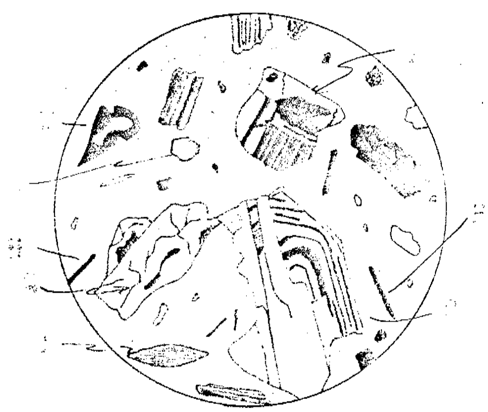

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The rhyolite agglomerate consists of rounded and angular fragments of older volcanic and intrusive rocks which range in size from 2 mm. to 1.5 feet. At least seven distinguishable types of rock have been noted occurring as fragments in the agglomerate though three of these are not present in the mapped area. The agglomerate presents a distinctive bedded appearance in the cliffs in Water Canyon and a sharp break near the top of the unit suggests that deposition was not continuous. Cave openings as large as 10 feet in diameter can be seen occassionally in some of the cliff faces and suggests areas where poor or incomplete cementation of the agglomerate fragments has resulted in the weathering out of the fragments.

The rhyolite agglomerate probably resulted from the forceful expulsion of a red rhyolite lava which brought up with it fragments which were torn from the basement rocks as well as from the sides of the vent. The even distribution of both large and small fragments of various types of rock throughout the vertical extent of the unit suggests that the lava was viscous enough or cooled quickly enough to prevent any sort of size or gravity separation to take place. The crude bedding and breaks between beds indicates that deposition was not continuous but rather successive waves of lava were ejected from the center of eruption.

Microscopically the rock consists of subround to round fragments of varying size and phenocrysts of quartz in a deeply iron stained glassy groundmass. Recognizable rock types include the middle banded member of the streaked rhyolite, the late trachytic andesite and a basic rock, which does not outcrop in the area, consisting of laths of plagioclase in a deep black groundmass. A few badly altered potash feldspar crystals are present but form an insignificant portion of the rock. The quartz is generally light gray to yellow and shows little or no strain or fracturing. The large proportion of primary quartz making up the rock has been taken to indicate the highly acid nature of the rock and though virtually no feldspars are present the unit has been termed a rhyolite agglomerate.

ANDESITE PORPHYRY: The andesite porphyry outcrops in a crude L-shaped belt in section 25 where it lies upon the rhyolite agglomerate with slight erosional unconformity. It appears to occupy a low area on the upper surface of the rhyolite agglomerate where it has been protected from erosion. It is also in fault contact with the younger late trachytic andesite and streaked rhyolite. A down faulted triangular block in contact with the streaked rhyolite is seen in sections 35 and 36 and an island of andesite porphyry surrounded by alluvium occurs at the junction of sections 25, 26, 35, and 36. The maximum observed thickness of the andesite porphyry is 100 feet but erosion has undoubtedly reduced the original thickness.

The unit consists almost entirely of flows except for a thin, lens- like tuffaceous breccia which occurs near or at the top of the unit. The breccia never exceeds 15 feet in thickness and is rather limited in areal extent. It contains angular fragments of earlier Tertiary volcanic rocks found in the area. A few badly weathered plagioclase crystals are the only observable phenocrysts in the breccia member.

The flow unit ranges in color from purplish red to pink and consists of white plagioclase crystals with a variable amount of biotite and hornblende in a fine grained, iron stained groundmass.

In thin section phenocrysts constitute about 30% of the rock. Zoned, subhedral oligoclase crystals ranging in size from 0.3 to 4 mm. make up about 85% of the phenocrysts. Small tabular hornblende crystals and occasional dark brown to black biotite flakes are present throughout the rock. Euhedral apatite and magnetite grains are accessory minerals. The groundmass is glass and heavily iron stained.

LATE RED RHYOLITE: The late red rhyolite lies unconformably upon various units including the rhyolite agglomerate, late trachytic andesite and streaked rhyolite in section 26 where it caps the east wall of Water Canyon about 2 miles south of its mouth. Its contact with underlying formations is thoroughly obscured by talus. In sections 34 and 35 it is in fault contact with the rhyolite porphyry on the east and the pink rhyolite on the north. The late red rhyolite attains a thickness of about 250 feet.

In the field it bears a very strong resemblance to the early red rhyolite and only the usually deeper red color and greater number of feldspar phenocrysts serve to distinguish the two units. Locally even these criteria do not hold true.

The composition of the two units in thin section is very similar. Phenocrysts of quartz, orthoclase and pleochroic hornblende comprise about 40% of the rock as they do in the early red rhyolite. The quartz in the younger rock is much strained and fractured unlike that of the early rhyolite unit. Orthoclase in both units is highly altered and at times completely replaced by calcite. The groundmasses of both rhyolite units are red and exhibit some flow banding though the banding is stronger in the late red rhyolite.

PINK RHYOLITE: The pink rhyolite, the youngest of the Tertiary effusive rocks in the mapped area and the equivalent of the pink rhyolite unit described by Loughlin and Koschmann (1942) in the Magdalena district, outcrops in sections 35 and 36 near the south end of the mapped area where it unconformably overlies the streaked rhyolite and is in fault contact with the rhyolite porphyry and the late red rhyolite. It reaches a thickness of 400 feet though this does not represent its original thickness since erosion has removed an unknown portion of it. Talus covered slopes normally obscure its lower contact.

The rock is uniformly pink and very fine grained with occasional phenocrysts of orthoclase and clear or smoky quartz.

In thin section the phenocrysts of euhedral quartz and orthoclase constitute 20% of the rock and are imbedded in a pinkish brown glassy groundmass. The quartz has a faintly yellow tinge and is usually fractured and considerably embayed and some phenocrysts show resorption affects about their peripheries. Orthoclase is generally twinned and judging from its somewhat high extinction angle (12° to 14°) contains an appreciable amount of sodium (Rogers and Kerr, 1942). Quartz and orthoclase vary from 0.3 mm. to 1.2 mm. in length. Except for a few biotite flakes there are no dark minerals present in the rock.

RHYOLITE PORPHYRY: The rhyolite porphyry outcrops in a broad, northeast trending band in the southwest corner of the mapped area where it forms the east wall of Water Canyon. It lies in fault contact with the purple andesite and the Carboniferous sediments along the Water Canyon fault while along its east border it is apparently faulted against the streaked rhyolite, late red rhyolite, and pink rhyolite. The only intrusive contact found was in the southeast quarter of section 23, where it is exposed on the east side of a low hill of rhyolite agglomerate bordering the east wall of the canyon. This exposure is the only evidence found for dating the unit in the volcanic sequence and serves only to date it sometime after the deposition of the rhyolite agglomerate. The situation in the southwest corner of the area is less certain. Although the unit was mapped with fault boundaries along both east and west contacts the possibility exists that these contacts are in part intrusive since the porphyry may have been intruded along pre-existing faults. The east boundary of the unit is obscured by stream gravels so that no definite evidence could be seen here though the near vertical walls of the rhyolite porphyry certainly suggest the presence of a fault. On the whole the lack of observable contact phenomena along the boundries, which would probably attend such an intrusion, suggests the presence of fault contacts.

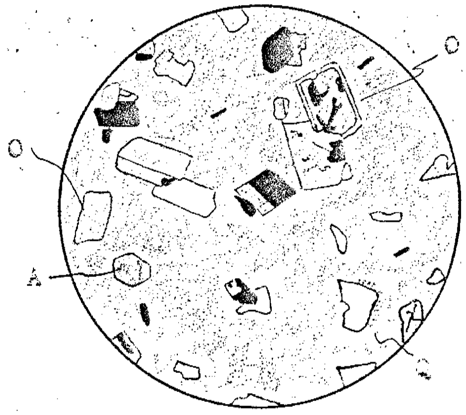
The rhyolite prophyry is grayish in color and consists of a siliceous groundmass with phenocrysts of pink orthoclase about 1.5 mm. long and glassy grayish quartz which at times reaches a diameter of 3 mm.

In thin section subhedral phenocrysts make up about 30% of the rock. Quartz averaging 2 mm. in diameter comprises 30% of the phenocrysts; it is rounded and usually exhibits a slight amount of fracturing.

A. Pink rhyolite. Euhedral orthoclase (o), partially resorbed quartz (Q) and apatite (A) in glassy groundmass.

B. Rhyolite porphyry. Sericitized orthoclase (O) partially replaced by calcite (C). Albite (A) and quartz (Q) also present.

C. Lamprophyre dike. Zoned plagioclase (P) and quartz grain (Q) completely replaced by calcite in mesh of andesine-labradorite (AL) laths. Many scattered magnetite grains (M)



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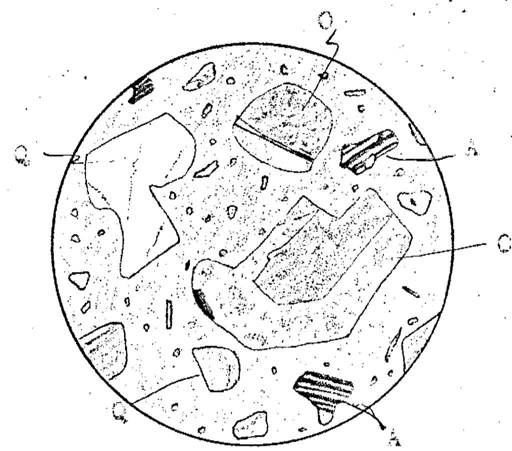

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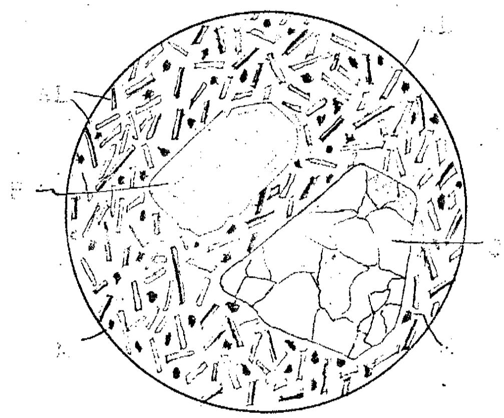

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Twinned orthoclase makes up about 50% of the phenocrysts and is much altered to sericite and partly replaced by calcite. Albite makes up the remainder of the phenocrysts and is usually not so thoroughly altered to sericite but some calcite replacement is evident. The feldspars average slightly under 1 mm. in length. Magnetite and highly altered augite (?), which has been completely replaced by calcite, iron oxide, and chlorite, are the accessory minerals. The groundmass is gray and glassy.

<u>Dike Rocks</u>

Few dike rocks are exposed in the Water Canyon area and these are restricted to the west side of the canyon. Though all are of Tertiary age and appear to have been localized along the same zones of structural weakness they vary widely in composition.

MONZONITE DIKES: North-south trending monzonite dikes are well exposed in the hills west of Water Canyon especially where streams have cut down through them as in sections 27 and 34.

The monzonite presents a somewhat varied appearance both in the field and in thin section. The dikes range in grain size from medium to coarse and it may be significant that the coarsest grained dikes are in the greenstone. This could reflect the relative depths of the intruded units at the time the dikes were emplaced.

Quartz is variable in amount from abundant to only minor quantities and both potash and plagioclase feldspars are present. The groundmass is generally fine grained and has a light green tinge. Some biotite is present.

The microscope reveals a porphyritic texture with phenocrysts of
quartz and subhedral to euhedral orthoclase and acid plagioclase in
a very fine grained groundmass of quartz and feldspar. The orthoclase
is usually twinned and it and the plagioclase are normally badly
altered and at times replaced by calcite. Where the amount of plag-
ioclase decreases and quartz increases the rock resembles a sodic
rhyolite. The greenish tinge seen in hand speciman is due to the
alteration of minor amounts of biotite to chlorite.

LAMPROPHYRE DIKES: Lamprophyre dikes, similar to those reported
by Loughlin and Koschmann (1942) in the Magdalena district, are found
in sections 26, 27, and 34 on the west side of Water Canyon. They
trend slightly east of north. Two dike types have been recognized in
the mapped area; one is a fine grained, dense, black rock which is
aphanitic in hand speciman. The other is greenish gray, porphyritic,
and characteristically weathers spheroidally.

Under the microscope the first type consists of a mesh of plag-
ioclase feldspar laths which range in composition from oligoclase to
andesine and average about .2 mm. in length. The laths form about
90% of the rock. The interstitial spaces are filled with irregular
chlorite aggregates and magnetite grains and a slight amount of
interstitial quartz. The chlorite may be an alteration product of a
primary mafic mineral. The type corresponds farily closely to Loughlin
and Koschmann's type 4.

The second variety is slightly coarser grained with a dense mesh
of andesine and labradorite laths averaging about 0.3 mm. to 0.4 mm.
in length. Phenocrysts of a euhedral, zoned plagioclase and a pyroxene,

probably augite, have been almost completely replaced by calcite. Some coarse quartz grains have also been replaced by calcite. Fine grained magnetite is abundant throughout the section.

While the lamprophyre dikes in the Magdalena Mountains are varied in several aspects they exhibit similarities which allow their grouping as a single unit. The groundmasses are characteristically composed of a felty aggregate of plagioclase laths which range in composition from albite to labradorite. Accessory minerals are usually augite and hornblende and all of the various dike types have been much altered with calcite, chlorite and quartz the common secondary minerals.

Quaternary Sediments

Alluvium and recent stream gravels have been differentiated in the study of the area. The alluvium is found extensively east of the face of the Magdalena Mountains where it lies against Tertiary volcanics and Precambrian granite and in the south-central portion of the mapped area where it lies atop the Tertiary volcanic sequence. Several small areas of terrace gravels were noted in both Water Canyon and South Canyon and their extent, while limited, is indicative of recent uplift which has resulted in the cutting of streams through the alluvium and the deposition of recent stream gravels. Most of the Tertiary volcanic units are recognizable in the alluvium and locally limestone and granite boulders are seen. The stream gravels, however, carry several types of intrusive rock fragments not present in the mapped area. The alluvium ranges in elevation from about 6000 feet on the plains east of the Magdalena Mountains to over 7000 feet atop the Tertiary volcanic plateau east of Water Canyon.

STRUCTURE

The Magdalena Mountains are a short, north-south trending block faulted mountain range consisting of a basement of Precambrian green-stone and granite which is unconformably overlain by Paleozoic sed-iments and Tertiary volcanic rocks. The range is located in that portion of the Basin and Range province (Fenneman 1930) known as the Rio Grande Depression (Kelley and Silver 1952). The mountains are bordered on the east by a downthrown fault block variously known as the Snake Ranch Flats or the La Jenze sub-basin which in turn is bordered on the east by the north-south trending Socorro and Lemitar Mountains. To the northwest the Bear Mountains and to the southwest the San Mateo Mountains border the Magdalena Range and the Tertiary and Quaternary rocks and structures found in these areas are believed to be genetically related to those in the Magdalena Mountains.

High angle normal faulting of the so called Basin and Range type (Gilbert 1874, 1928 and King 1878) form the most obvious structural features in the Magdalena Mountains but periods of folding and erosion have played an important part in the structural and physio-graphic development of the range.

An attempt has been made to relate the structural features present in the Water Canyon area to those reported by Loughlin and Koschmann (1942) in the Magdalena District and to major structural features of central New Mexico. Many assumptions are based on an admittedly meagre amount of geologic mapping and a greater amount of personal study, both in the field and in the literature, of central New Mexico geological features, and conclusions have been drawn with a full realization of these limitations kept in mind.

Unconformities

Two major angular unconformities have been noted in the Water Canyon area as well as throughout the Magdalena Mountains. These occur between the Precambrian rocks and the Carboniferous sediments and between the Carboniferous sediments and Tertiary volcanics. In addition to these an unconformity occurs between the Tertiary volcanics and Quaternary sediments which, however, was not studied in any detail during the course of this investigation. Several minor erosional and angular unconformities occur within the Paleozoic sequence of formations as well as within the Tertiary volcanic sequence.

PRECAMBRIAN-CARBONIFEROUS UNCONFORMITY: Pre-Carboniferous rocks, which are widespread in southern New Mexico, thin to the north and rarely appear above latitude 34° (Darton 1928). Such absence is probably due in part to pre-Carboniferous erosion which removed any older Paleozoic sediments that may have been present and exposed Precambrian rocks. In the Magdalena Mountains the Precambrian rocks were reduced to a nearly level or gently undulating surface upon which the Carboniferous sediments were deposited. Below the unconformity the greenstone strikes roughly north-south and locally, as in North Fork Canyon some distance to the west of the mapped area, dips at high angles to the east, while above the unconformity the

Carboniferous sediments strike N 15° W and dip steeply to the southwest.

Unconformities between Precambrian rocks and Carboniferous sediments of the type exposed in the Magdalena Mountains are common throughout northern New Mexico and have been reported in the Socorro and Lemitar Mountains (Darton 1928), the Ladron Peak area (Lasky 1932) Sandia Mountains (Ellis 1922), Manzano and Los Pinos Mountains (Darton 1928).

CARBONIFEROUS-TERTIARY UNCONFORMITY: Tertiary volcanic rocks in the Magdalena Mountains lie upon the eroded surface of the Carboniferous and, as in the Magdalena district (Loughlin and Koschmann 1942), Permian sediments with angular unconformity. The basal volcanic units are locally in contact with various beds of the Sandia formation, Madera limestone, and Abo sandstone indicating local differences in amounts of erosion as does the absence of the Abo sandstone in the Water Canyon area. Such differences in degree of erosion together with the change of strike of the Paleozoic sediments in the Magdalena district from N 15° W in the main range to N 30° E in the Granite Mountain area to the west (Loughlin and Koschmann 1942) indicate that the sediments were arched and beveled in pre-volcanic time.

The Carboniferous sediments below the unconformity strike N 15° W and dip about 30° southwest. Above the unconformity in the Water Canyon area the Tertiary volcanic rocks strike from 10° to 30° to the northeast and dip to the northwest at angles of from zero to 15°. Minor exceptions to these trends are noted below. Farther north

Loughlin and Koschmann (1942) report that the volcanic units strike almost due north and dip 25° to 30° westward.

Angular unconformities at the base of the Tertiary system which separate Tertiary volcanic and sedimentary rocks from underlying Paleozoic and Mesozoic sediments have been noted in many places throughout central New Mexico. In the Socorro Mountains Lasky (1932) reports Tertiary volcanic units lying unconformably upon tilted upper beds of the Magdalena Group. Winchester (1921) reported nearly flat lying beds of the Tertiary Datil formation unconformably overlying folded Cretaceous sediments in the Alamosa Creek Valley only 20 miles northwest of the mapped area. In the Caballo Mountains Kelley and Silver (1952) have shown that Tertiary sediments overlie Pennsylvanian and upper Cretaceous formations with varying degrees of angular unconformity from slight to sharp. Darton (1928) reported Tertiary volcanics and sediments overlapping folded Cretaceous sediments in the area around the Taylor coal basin in southeastern Socorro County and Wilpolt et al (1946) indicate similar conditions in the Chupadera Mesa area.

MINOR UNCONFORMITIES: A slight angular unconformity between the Abo sandstone and the Madera limestone reported in several parts of New Mexico (Darton 1928, Lee and Girty 1909) is present in the Magdalena district (Loughlin and Koschmann 1942) and may be a reflection of the more intense late Pennsylvanian Marathon disturbances noted in southwest Texas (Schuchert and Dunbar 1947).

Minor erosional unconformities occur within the Tertiary volcanic sequence and are indicated by the presence of pebble and cobbles in the basal zones of several volcanic units of material derived from underlying formations. Such unconformities occur between the early trachytic andesite and streaked rhyolite and between the streaked rhyolite and late trachytic andesite.

Erosional unconformities of greater magnitude occur at the base of the rhyolite agglomerate, at the base of the late red rhyolite and at the base of the pink rhyolite. In all three cases erosion has removed one or more of the earlier volcanic units and in the case of the late red rhyolite and pink rhyolite faulting and some tilting as well as erosion preceeded their deposition. Unlike the earlier members of the volcanic sequence the late red rhyolite and pink rhyolite do not dip to the northwest. The absence of any recognizable flow structures in either of these units together with the obscured nature of their lower contacts makes determination of their dips and strikes difficult but in the southern portion of section 26 and the northern portion of section 35 they both appear to dip gently to the south. The extent to which these supposed dips are due to original dip or later tilting or both could not be determined. In the absence of concrete evidence of their true dips no attitudes have been recorded for the late red rhyolite and pink rhyolite on the geologic map (fig. 2).

Similar unconformities have been reported by Loughlin and Koschmann (1942) in the Magdalena district and they also report the existence of a sharp angular unconformity separating a lower series and upper series of volcanic units. The lower series is absent or buried in the Water Canyon area.

Jointing

Jointing is a prominent feature in only three of the geologic units exposed in the Water Canyon area. Both the greenstone and granite exhibit well developed joint systems and the middle banded member of the streaked rhyolite exhibits a type of jointing probably directly related to its mode of deposition.

JOINTING IN GREENSTONE: The greenstone exhibits three well developed joint systems which cause it to weather to angular blocks. The peculiar weathering is best displayed in the more massive varieties of greenstone and with an increase in degree of schistosity such weathering forms are obscured. One joint set is almost vertical and strikes roughly N 25° E. The other two sets belong to what appears to be a conjugate joint system striking about N 40° E. One set dips about 70° southeast and the other 12° to 16° northwest.

JOINTING IN GRANITE: Loughlin and Koschmann (1942) report three major joint sets occurring in Precambrian granite. One trends north and dips east about normal to the upper contact of the granite while another trends northeast and dips moderately to steeply to the northwest. The third set parallels the upper contact of the granite. Only the north-trending set dipping steeply to the east was observed in the mapped area.

Evidence with which to date the joint sets in the granite and greenstone is lacking in the Water Canyon area but Loughlin and Koschmann (1942) believe that while some were formed in Precambrian time many developed during the fracturing that attended the Laramide and Tertiary disturbances.

JOINTING IN STREAKED RHYOLITE: A type of jointing or platy parting apparently unrelated to diastrophic forces is found in the middle banded member of the streaked rhyolite. It is best exhibited on the east-facing cliffs of the range near the border of sections 24 and 25 where the unit displays a type of color banding usually regarded as a flow structure. The banding is extremely straight and nearly vertical but the strike of the bands is difficult to determine due to the vertical nature of the cliff face. A study of the rock at the base of the cliff indicates that the jointing or parting always parallels the flow banding and both are probably related to minor differences in composition between bands. The banding and attendant jointing indicate that the planes of flow were nearly vertical and this could be interpreted to mean either that the lava was moving upward, in which case the outcrop represents a portion of a volcanic vent, or that the lava was moving down a steep slope and that the steepness of the resulting flow bands was later increased by faulting movements.

Folding

Though high angle faulting has dominated the structural development of the Magdalena Mountains folding appears to have played an important part in that development. The variation in amount of erosion of the Carboniferous sediments throughout the range was discussed previously in a consideration of the Carboniferous-Tertiary unconformity and it was suggested that the region was arched and beveled prior to the deposition of the Tertiary volcanic rocks. A combination of faulting, erosion, and volcanic cover has since obscured the magnitude and trend of such folding throughout much of the range but Loughlin and Koschmann (1942), basing their opinion on the nature of the change in strike of the Paleozoic sediments in the northern part of the range, suggest that the fold was a north-plunging anticline. Further evidence for such folding are the west dipping reverse faults noted by Loughlin and Koschmann (1942) in the Magdalena district. Such faulting is more readily associated with folding that with the high angle gravity type of faulting found in the Magdalena Mountains.

The dip of the Paleozoic sediments throughout the mapped portions of the Magdalena Range is prevailingly westerly and can be attributed, in part at least, to westward tilting which attended Tertiary faulting. However, the easterly dips reported by Wells (1918) and observed by the author in the southeast portion of the range cannot be explained in this way but do represent evidence in favor of the existence of a pre-volcanic north-sound-trending fold.

The absence in the Magdalena Range of Mesozoic formations and clearly defined structures which could be correlated with those in surrounding regions makes precise dating of the folding impossible. However, Laramide compressional forces are known to have produced folds and overthrusts in the central New Mexico region surrounding the Magdalena Range (Darton 1928, Winchester 1921, Wilpolt et al 1946, Kelley and Silver 1952) and it is inferred that they were active to some degree during the earliest stages of deformation of the Magdalena Range and that they produced a north-trending anticlinal structure the west limb of which is represented by the range.

Faulting

High angle faults which form the major structural features in the Water Canyon area, as well as the entire Magdalena Range, are predominately normal faults though several may be reverse faults. Poor exposures and nearly vertical attitude of all faults make determination of this point difficult (see fig. 4). Loughlin and Koschmann report the presence of several minor west dipping reverse faults in the Paleozoic sediments in the Magdalena district (Loughlin and Koschmann 1942) but none were recognized in the Water Canyon area.

Two fault systems are present in the Water Canyon area. One strikes from a few degrees west of north to N 50° E while the other strikes from N 15° to 40° W. The fault pattern indicates that the northeast trending faults are of a younger age though the lack of fault intersections and offsetting of faults makes this rather speculative.

The fault or fault zone bounding the east side of the Magdalena Range trends roughly N 45° W in the Water Canyon area. Its exact position and trend are not known though if, as is thought, the face of the range represents an eroded fault scarp the boundary fault probably parallels the range front to a fair degree. North of Water Canyon the fault cuts Precambrian granite up to the northern end of the range while from Water Canyon south progressively older members of the Tertiary volcanic sequence are cut by it. The throw on the fault is indeterminate but it probably exceeds 5500 feet. While no direct evidence exists, the eastern face of the range is probably bounded by a fault zone rather than a single fault. Loughlin and Koschmann (1942) have noted the presence of a series of small step faults on the granite slopes near the crest of the range in the Magdalena district which indicate the presence of such a zone.

The Water Canyon fault is the most prominent of the faults in the mapped area. Its trend is well defined by Water Canyon which is an excellent example of a fault controlled stream. The maximum throw on what is probably a vertical fault plane cannot be precisely determined but it is probably in excess of 2500 feet. The western or up-thrown block of granite, greenstone, Carboniferous sediments, and purple andesite is now in contact with a series of Tertiary volcanic rocks to the east of the fault. The progressively younger age of the formations from north to south along the west side of the fault is, in part, due to topographic relief but may also be due in part to a decrease in the throw from north to south. At several places along the fault, as in sections 26 and 34, fault "slices" border the main break on the upthrown side. This apparently resulted from differential movement of narrow, elongate wedges along the fault.

The northeasterly trending fault in the east portion of section 34, the northwest corner of section 35 and the southwest quarter of section 26 closely parallels the trend of the Water Canyon fault and marks the boundary between the rhyolite porphyry and the streaked rhyolite, late red rhyolite and pink rhyolite. The nature of this contact was discussed in the description of the rhyolite porphyry and it was suggested that the rhyolite porphyry might have been emplaced along a pre-existing fault thus making the contact partly intrusive. It has not been possible to determine the exact age relationship of the rhyolite porphyry with respect to the rest of the volcanic sequence and this fact together with a lack of evidence concerning its mode of emplacement makes determination of the relative movements on either side of the fault and its throw impossible. The short narrow segment of rhyolite porphyry exposed on the east side of the fault in section 26 suggests that the fault cuts the rhyolite porphyry and is, therefore, younger than it. However, the contact of the rhyolite porphyry segment and the volcanic units on the east is obscured by alluvium and no positive conclusions concerning the nature of its contacts can be drawn. The fault forks in section 26 and its two prongs enclose a down-dropped wedge of late red rhyolite which is cut off on the north by a fault of northeasterly trend.

A vertical fault closely paralleling the trend of the Water Canyon fault is present in sections 23, 24, and 26. Near the fault's northern extremity a block of rhyolite agglomerate has been relatively down-thrown on the west side. The throw at this point is about 100 feet. To the south the fault cuts a low hill of agglomerate and has exposed a segment of the rhyolite porphyry. The minimum throw at this point is about 80 feet but it is probably in excess of 100 feet and may be as great as 600 feet.

A short slightly northwest-trending fault in the west central part of section 26 cuts a small outcrop of purple andesite on the east and has thrown the rhyolite agglomerate down about 300 feet placing it in contact with the upper member of the streaked rhyolite and the late trachytic andesite. The northern end of the fault is concealed by alluvium while at its southern extremity it is cut by the late red rhyolite indicating that some faults were active during the late period of volcanic activity.

The north to slightly northeast trending monzonite and lamprophyre dikes on the west side of Water Canyon in most cases are fault or joint controlled and appear to have been intruded along planes of structural weakness.

Interpretation of Laramide Structure

Evidence of pre-volcanic folding which arched the area about the Magdalena Mountains into a roughly north-trending anticline have been mentioned previously. They include local variation in amount of erosion, change of strike of the Paleozoic sediments in the northern end of the range, the easterly dip of sediments in the southeast portion of the range and westward dipping low angle thrust faults. These factors are believed to offer strong arguments in favor of such folding. The Laramide age of the compressional forces which produced the folding is inferred from our knowledge of the existence of such forces in regions surrounding the Magdalena Range in central New Mexico.

The direction in which such supposed forces acted is mostly conjectural though the west to slightly southwest dips found in most of the range suggest that such forces acted in a roughly east-west direction. Further evidence of this, though of a highly speculative nature, exists in the fault pattern found in the Water Canyon area.

The excellent alignment of dikes and faults paralleling the Water Canyon fault suggests that the trend of the Water Canyon fault defines the trend of a wide zone of structural weakness. Such a zone is oblique to the supposed fault zone bordering the Magdalena Range on the east and the two zones might be related to the strain ellipsoid (Billings 1942) and interpreted as shear zones produced by compressional forces. The orientation of the supposed shear zones suggests that the forces capable of producing them probably acted in an east-west direction. The faulting was not necessarily the result of such shearing since there was an appreciable period of time between the onset of the forces which might have produced the shears and the faulting, most of which took place after the end of the late period of volcanic activity. It appears more likely that the forces which produced the shear zones subsided some time before the end of the period of volcanic activity. The down-dropping of the east limb of the fold may have resulted from tensional stresses which followed the relaxation of the compression. Nevin (1950) states, "After the folding and smashing of an area by compressive forces, relaxation may set in and give rise to major high angle normal faults. Some of this settling may be the result of carrying the fold too far. That is, the folds are unstable without the support of active compression. More probably, as the compressive forces diminish, the rocks, because of their elasticity and resilience, compensate partially for the previous crustal shortening by active extension, vertical relaxation, and normal faulting."

Alternatively, the removal of large masses of molten material from the basement may have left the overlying rocks without support and could have resulted in the settling of large blocks along high angle faults whose orientation was determined by pre-existing zones of structural weakness.

Loughlin and Koschmann (1942) have suggested that faulting began in Laramide time and continued throughout the volcanic period. In the Water Canyon area, however, all of the faults, with the exception of the slightly northwest-trending fault in west central section 26, appear to have been formed after the end of volcanic activity. The fault in section 26 is cut by the late red rhyolite and must have formed prior to the deposition of the late red rhyolite. It is possible that recurrent movements took place along the faults exposed in Water Canyon all during the period of volcanic activity but except for the previously mentioned fault no evidence of this was found.

Adjustment along faults appears to have been continuous from the end of the period of volcanic activity to the present. Such recent adjustments are indicated by the increase in stream gradient which resulted in the dissection of Quaternary alluvial terraces and by the presence of a north-trending fault scarp which cuts recent alluvium at the northeast end of the Magdalena Range.

ORE DEPOSITS

Only two mines, neither being operated at present, are located within the mapped area. These are the Buckeye Mine in Copper Canyon and a manganese mine on the east wall of Water Canyon in section 26. Some detailed work was done at the Buckeye Mine in August, 1951 when the author assisted Dr. C.T. Smith in the preparation of surface and underground geologic maps. Only a cursory examination of the manganese mine was made during the course of the mapping in the Water Canyon area. Discussion of the two ore occurrences will be brief.

Manganese Mine

The manganese mine, which during World War I reportedly produced something in excess of $50,000 worth of ore, is now completely worked out. The deposit occurred in a brecciated zone of the upper member of the streaked rhyolite. The ore, which consisted of banded and botryoidal psilomelane and associated quartz and calcite, was localized by a set of northeast trending joints which roughly parallel the Water Canyon fault. The deposit was one of many such low temperature manganese deposits occurring in fractured Tertiary volcanic rocks which are found throughout the southeastern portion of the Magdalena Mountains.

Buckeye Mine

Copper, lead, silver and some gold mineralization was exploited in the Buckeye Mine in the latter part of the 19th century. The mine was developed on two levels but work was abandoned in 1901 when water completely filled the lower level. It was still filled at the time of the examination. Mineralization of the Kelly limestone is probably genetically related to the Tertiary monzonite stocks and the ore bearing solutions are thought to have been localized along a low angle transeverse fault trending roughly N 30° E. Only one record of an ore shipment from the Buckeye Mine is known. The shipment was made in 1917 when 53 tons of ore averaging 0.02 oz. gold, 2.79 oz. silver, and 5.57% copper were sent to the smelter. Virtually no ore reserves were in sight at the time of the examination.

Both in the Magdalena district and Water Canyon area ores appear to have been deposited in open spaces or favorable limestone horizons from solutions associated with Tertiary intrusive rocks. The solutions appear to have been localized by Tertiary faults.

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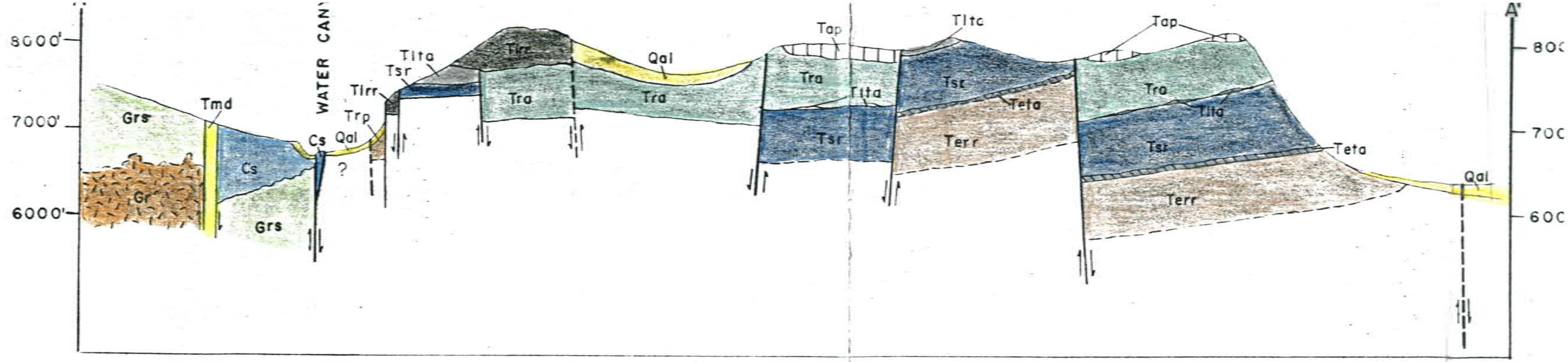
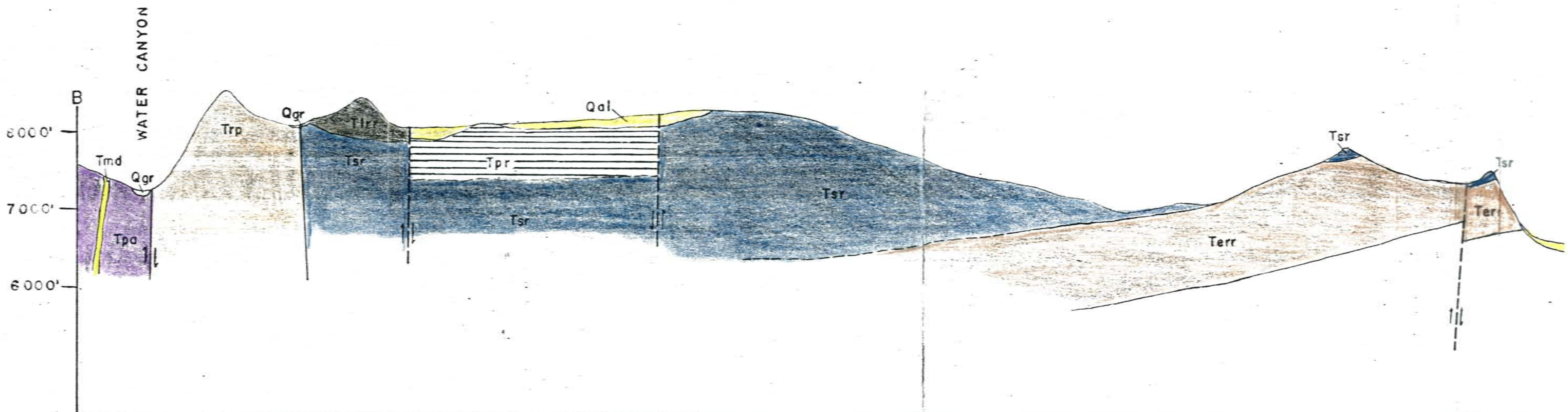


Section along line A—A'



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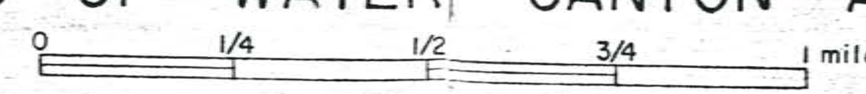
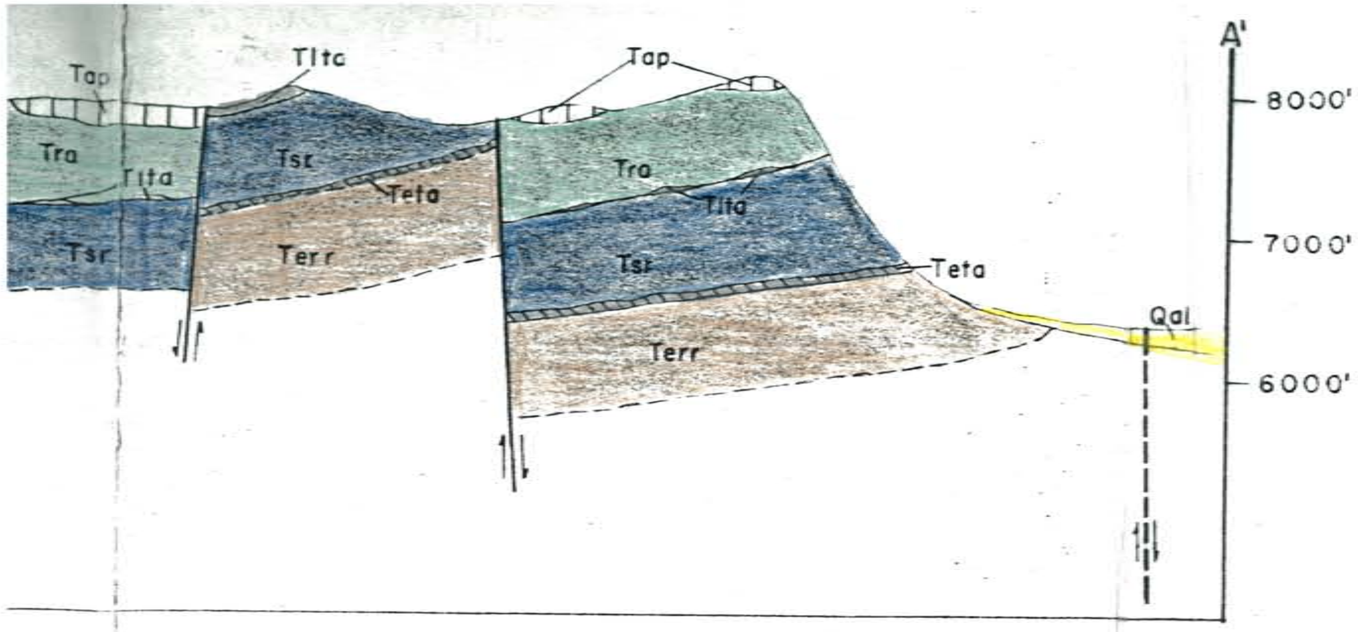
GEOLOGIC SECTIONS OF WATER CANYON AREA, NEW MEXICO





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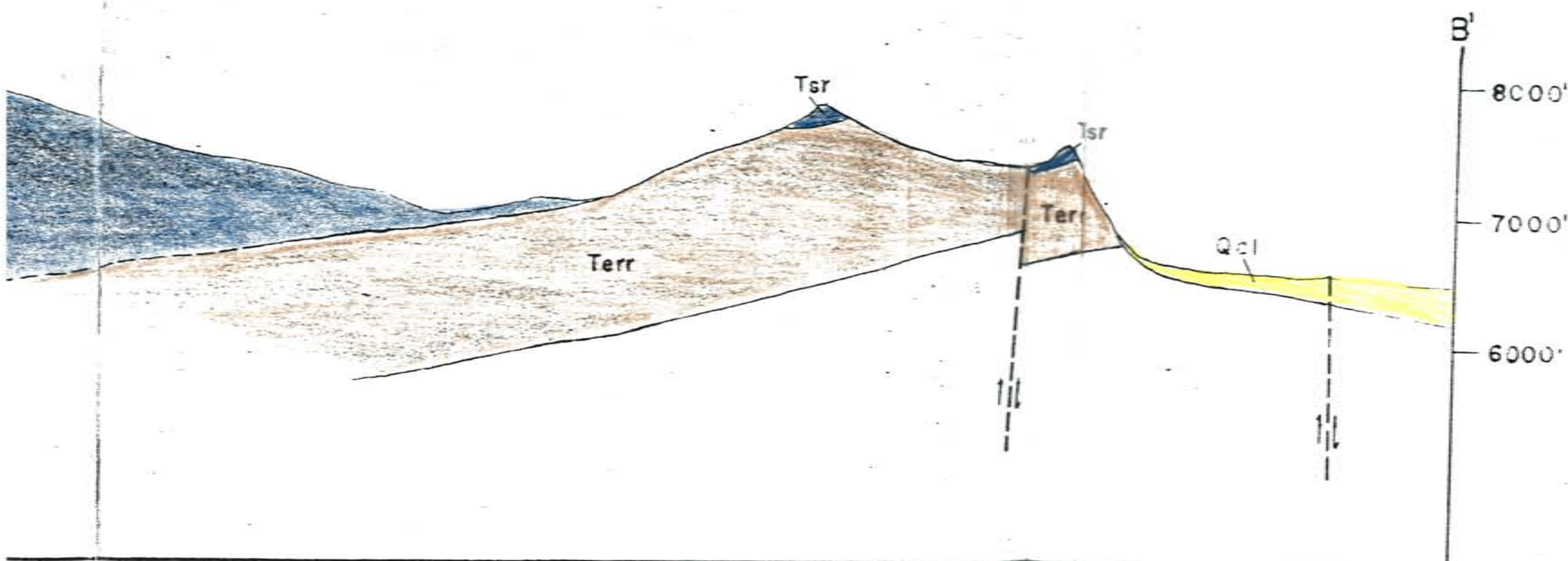

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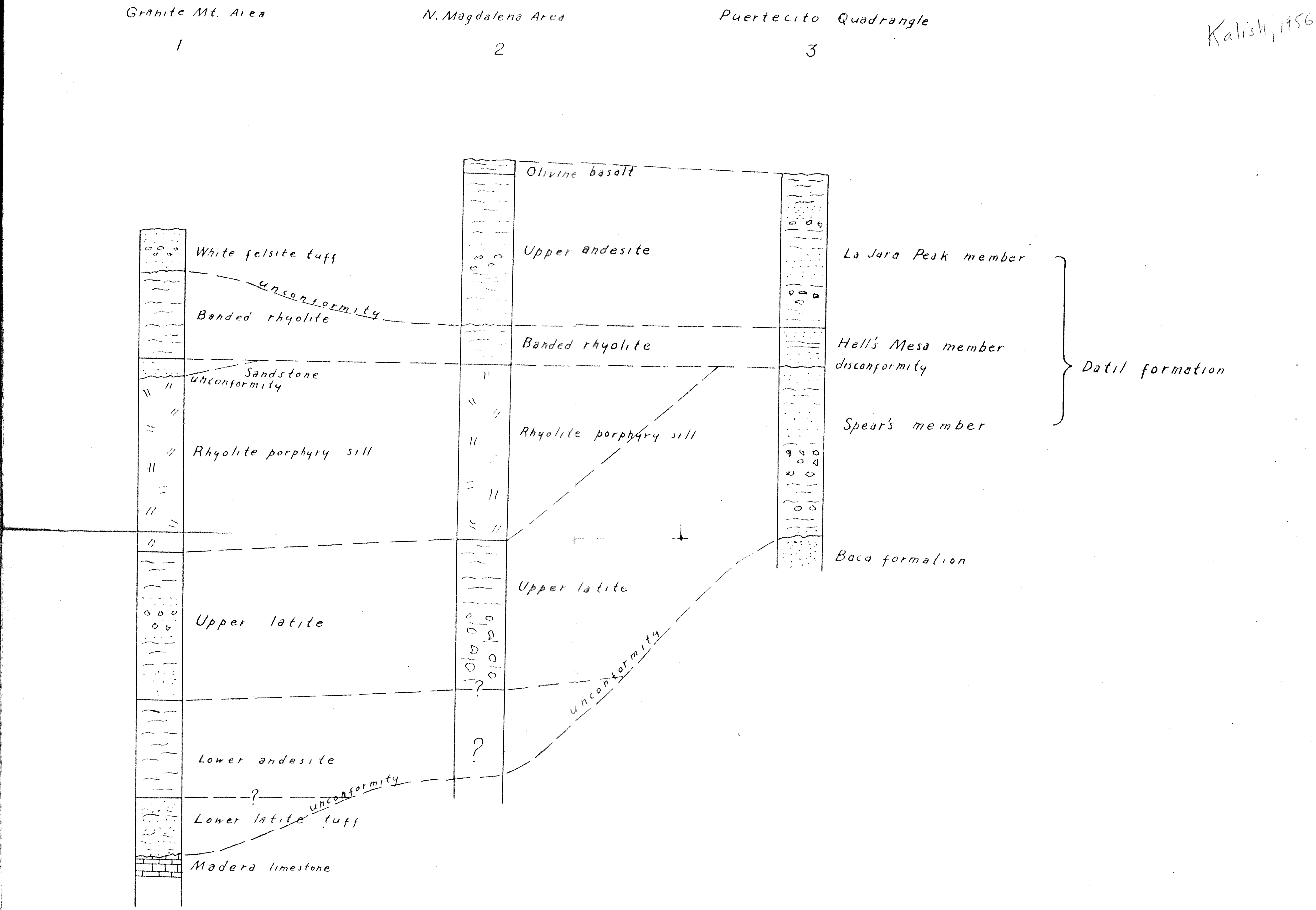
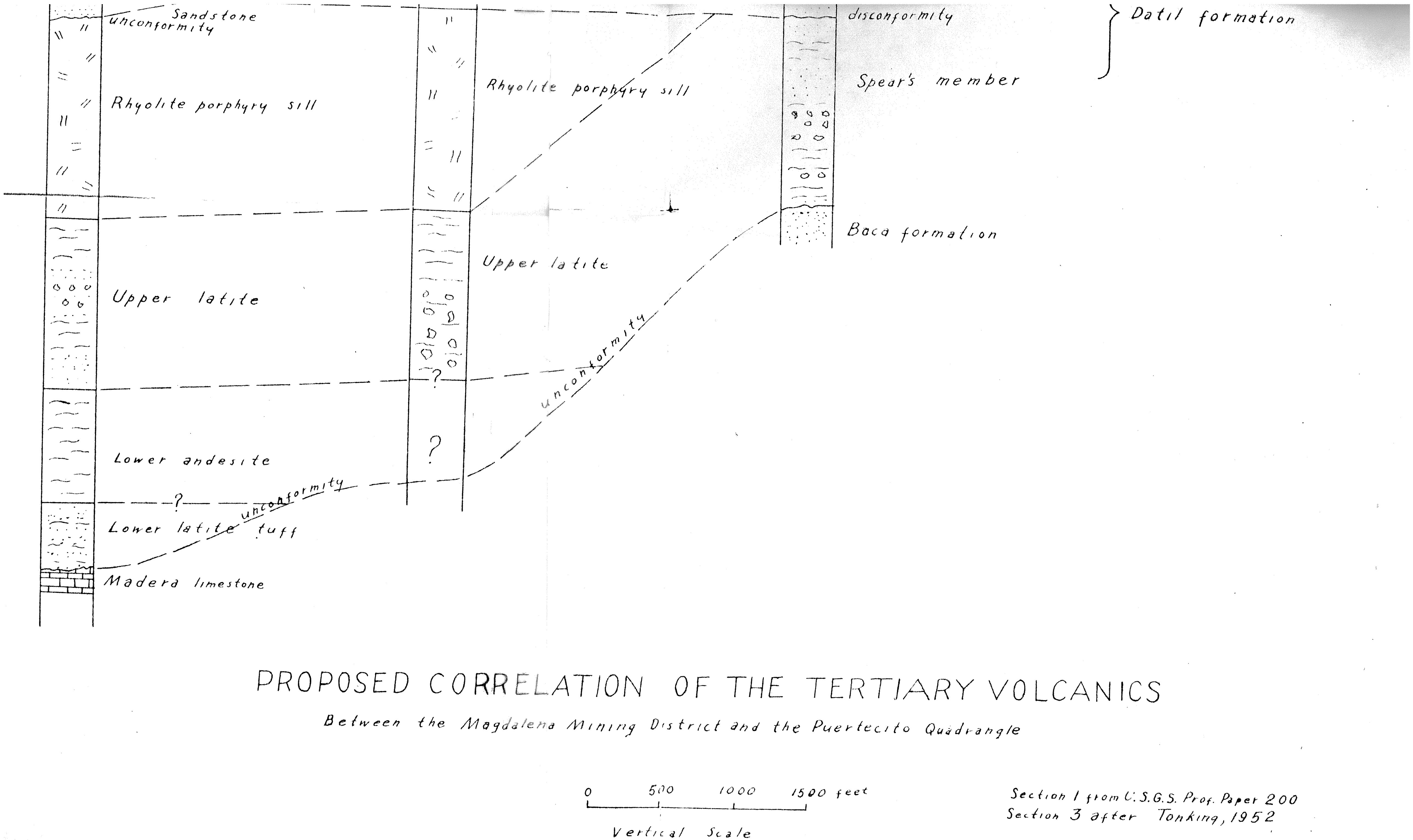
TER CANYON AREA, NEW MEXICO

1/2 3/4 1 mile

Fig. 4



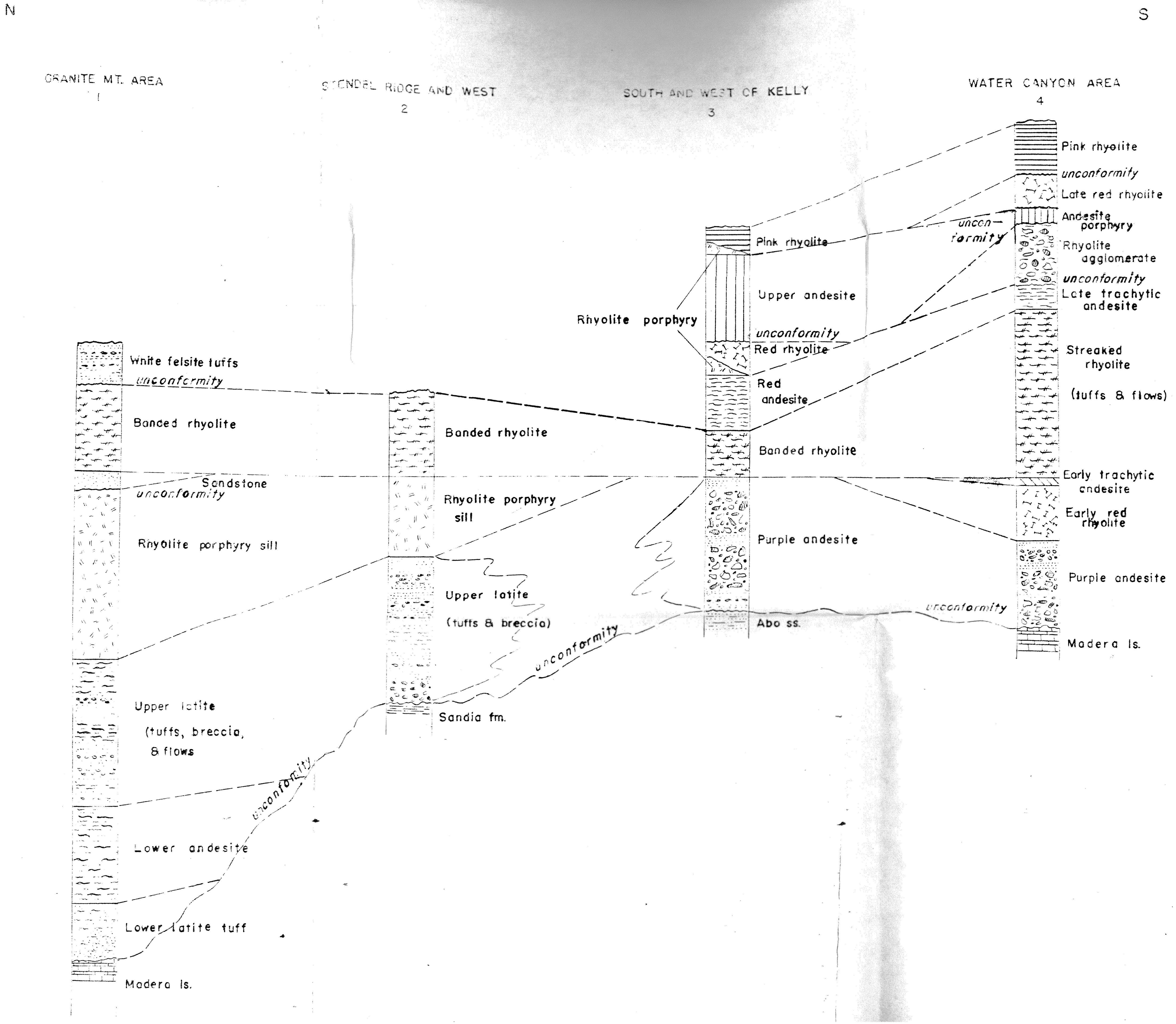
PROPOSED CORRELATION OF THE TERTIARY VOLCANICS

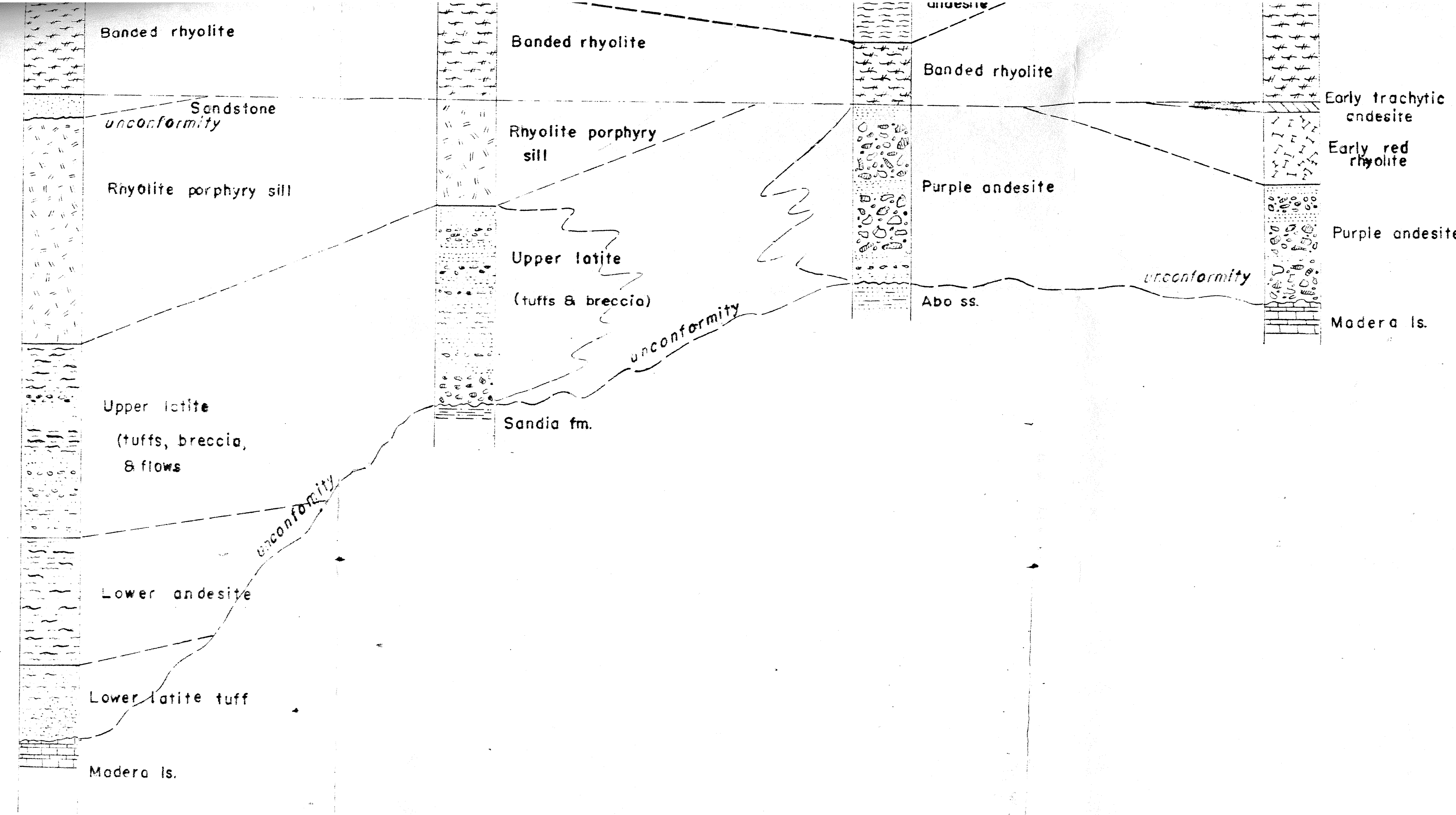


PROPOSED CORRELATION OF THE TERTIARY VOLCANICS

Between the Magdalena Mining District and the Puertecito Quadrangle

Section 1 from U.S.G.S. Prof. Paper 200
Section 3 after Tonking, 1952


N
S
GRANITE MT. AREA
1
STENDEL RIDGE AND WEST
2
SOUTH AND WEST OF KELLY
3
WATER CANYON AREA
4
White felsite tuffs
unconformity
Banded rhyolite
Sandstone
unconformity
Rhyolite porphyry sill
Upper latite
(tuffs, breccia,
& flows
Lower andesite
Lower latite tuff
Madera ls.
unconformity
Banded rhyolite
Rhyolite porphyry
sill
Upper latite
(tuffs & breccia)
Sandia fm.
unconformity
Pink rhyolite
Rhyolite porphyry
Upper andesite
unconformity
Red rhyolite
Red
andesite
Banded rhyolite
Purple andesite
Abo ss.
unconformity
Pink rhyolite
unconformity
Late red rhyolite
Andesite
porphyry
uncon-
formity
Rhyolite
agglomerate
unconformity
Late trachytic
andesite
Streaked
rhyolite
(tuffs & flows)
Early trachytic
andesite
Early red
rhyolite
Purple andesite
Madera ls.



Sequence of effusive igneous rocks in the Magdalena Mts.

500 0 500 1000 1500 feet
Vertical scale

Sections 1,2,3 from U.S.G.S Prof. Paper 200