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Igneous Geology Of The Rio Puerco Necks, Sandoval And Valencia Counties, New Mexico.

William Travis Brown Jr.

THE UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO 87106

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Peter J. Modreski U.S.G.S. Denver, CO	10/28/87
Lewis T. Hagman U.N.M.	10/19/88

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Title Igneous Geology of the Rio Puerco Necks, Sandoval and Valencia Counties, New Mexico

William Travis Brown, Jr.
Candidate

Geology
Department

Art Stea
Dean

2-7-69
Date

Committee

A. M. Kudo
Chairman

Lee A. Woodward

J. Paul Fitzsimmons

IGNEOUS GEOLOGY OF THE RIO PUERCO NECKS, SANDOVAL AND VALENCIA COUNTIES, NEW MEXICO

By
William Travis Brown, Jr.

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
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ABSTRACT OF THESIS

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Abstract

In the Rio Puerco valley of Valencia and Sandoval Counties, New Mexico, immediately east of Mount Taylor and its associated lava flows are a series of ten prominent and exposed basaltic rocks. These bodies consist of alkali basalts exhibiting no systematic mineralogic or compositional trends throughout the area. The alkali basalts are composed of olivine, augite, plagioclase (labradorite), and opaques in a trachytic to felty groundmass. Each neck was emplaced by means of a convection cell mechanism that allowed the surrounding Cretaceous sediments to remain undisturbed by the intrusion.

Contained in the alkali basalts are ubiquitous ultramafic inclusions of lherzolite and websterite, lherzolite being predominant. Little or no reaction zone is present between the inclusions and the basaltic host. These inclusions and the alkali basalts originated at depths probably in the range of 35-40 kilometers. Further, the inclusions were incorporated in the basalt from the mantle as it moved upward to its present position. They are not cumulates crystallized from the basalt but represent the residue of partial fusion of mantle material.

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LOCATION AND ACCESSIBILITY

The area investigated in this report comprises approximately 300 square miles, including portions of Sandoval and Valencia Counties, New Mexico. The area is delineated by latitude 35°37'30" N on the north, longitudes 107°22'30" W on the west, 107°5'0" W on the east, and latitude 35°07'30" N on the south (Fig. 1). The eastern boundary is roughly coincident with the western edge of Mesa Prieta, whereas the western edge is roughly on a north-south line passing through the pueblo of Seboyeta, New Mexico. The locations of the igneous bodies under investigation are situated on either side of a line extending from Cabezon to Seboyeta Peak.

The thesis area lies within the Rio Puerco Trough, which exists as the western edge of the larger Rio Grande Trough. To the immediate west of the area is the Zuni Uplift and to the south is the Lucero Uplift. Cretaceous sediments of the Mesaverde and Mancos Formations in the area are generally flat lying with a 1 degree dip to the east. The outstanding landforms are the isolated mesas and the igneous bodies exhibiting between 500 and 1,500 feet of relief, by far

the most striking physiographic features of the Rio Puerco valley. Drainage in the area is into the Rio Puerco, which flows south and joins the Rio Grande outside the area under study.

The peaks themselves are surrounded by steeply sloping hills covered with coarse basaltic talus at the base of each of these bodies. Outlying but closely associated with many of the peaks are unusual accumulations of basaltic material on knolls and extending along the slope sides, probably indicative of shallow subsidary intrusions. Exposed apophyses are evident in numerous locations adjacent to the larger, more impressive igneous masses.

The peaks may be reached by unimproved dirt roads from the north at a turnoff designated by road signs nineteen miles northwest of San Ysidro, New Mexico, on New Mexico Highway 44. From the south, the interior of the area is most easily reached by turning off U. S. Highway 66 immediately west of the Rio Puerco Bridge, seventeen miles west of Albuquerque, New Mexico. An alternate route from the south is through Seboyeta, New Mexico, where New Mexico Highway 279 becomes unpaved. This route provides an excellent means of reaching Cerro Negro and Seboyeta Peak. These peaks as well as the outlying locations of Cabezon Peak, Cerro de Guadalupe,

Cerro Vacio, Cerro Cochina, and Cerro Chato may be reached in good weather by passenger car, though travel within the interior of the area necessitates a vehicle equipped with four wheel drive, for the roads are privately maintained and frequently in poor condition. One may drive to within convenient walking distance of each peak by this means.

Previous Work

Numerous reports mention this area and its larger peaks as landmarks in conjunction with Mount Taylor. The earliest recorded reference was made by Spanish explorers traveling across the area. After the time of the Conquistadores the stagecoaches carrying passengers would often pass within sighting distance of the entire igneous field.

Many later and very recent studies have dealt more specifically with the geology of this area, though few have actually investigated explicity the igneous rocks and their relationships either with each other or with Mount Taylor. Detailed work was completed on the igneous lithologies of the area, however, by C. E. Dutton (1885) when he described the rocks of the area in hand specimen and visited a number of peak locations. Dutton's work deals primarily with the association of the igneous bodies with a lava sheet supposedly extending from Mesa Chivato on the west to Mesa Prieta on the

east. The work is on a broad scale and only hand specimen lithologic descriptions are given along with detailed descriptions of the peaks. Dutton further discussed the interrelationships and intrarelationships concerning jointing patterns and the character of the breccia associated with the many basaltic masses. Later D. W. Johnson (1907) visited the area and studied more exclusively the igneous bodies in the Rio Puerco valley. His work strongly supports that of Dutton with an accumulation of more specific facts and numerous plates and drawings. Johnson considers various hypotheses concerning the origin of the bodies, dispelling many and concluding that each body is a remnant of volcanic activity directly associated with the Mount Taylor episode.

Perhaps the most thorough and exhaustive study of the area in the Rio Puerco valley was conducted by C. B. Hunt (1937). Hunt begins his discussion dealing chiefly with Mount Taylor and its associated lava flows and then continues his discourse with visits to many of the individual locations of the various bodies, supplementing his text with numerous plates and detailed diagrams. Hunt's work is even more detailed than Johnson's though based largely on Johnson's previous work in the area. Hunt carefully describes and explains the developmental processes for the features now

observed at each of the locations and provides megascopic descriptions of the rocks, even extending his interpretations to bodies observed from as far as a mile away. Hunt's work also deals with the structural relationships possibly governing the previously mentioned lava cap, but generally indicates strong influence by the theories of both Dutton and Johnson.

Recent but more specific work was completed by George Brunton (1952) in the vicinity of Cabezon Peak. Brunton's work is the first documented petrographic study of the lithology of any of the igneous bodies in the Rio Puerco valley. His work, however, pertains primarily to the mineralogy of augite inclusions found in a dike some three miles southwest of Cabezon Peak at Cerro de Guadalupe. He proposed no origin for the basaltic bodies, though he did propose assimilation of the sediments by the magma and fractional crystallization to produce the unusual augite crystals.

Numerous other reports and papers have been written concerning this area's stratigraphy and paleontology. The information provided by these papers is beyond the scope of this study and will not be considered further.

Scope and Purpose

This study is concerned exclusively with the ten basaltic peaks in the Rio Puerco valley east of Mesa Chivato on the eastern edge of the Mount Taylor flows. The peaks are, from north to south, Cabezon Peak, Cerro Cochino, Cerro de Guadalupe, Great Neck Peak (Senora de Las Lagunitas de Santa Rosa), Santa Rosa Peaks (Santa Rosa and Jacabo), Cerro Chato, Cerro Vacio, Cerro Negro, and Seboyeta Peak. These basaltic bodies extend roughly southwest from Cabezon as prominent, isolated features in the Rio Puerco valley. Each peak is surrounded by talus slopes lying on the shales and sandstones of the Mesaverde and Mancos Formations of Cretaceous age.

The purpose of this study is to determine the mineralogical composition of each of these bodies through petrographic and chemical examinations. With the petrographic information the intrarelationships can be established as well as the relationships of these bodies to the larger volume of Mount Taylor eruptions and flows. A prime consideration in this study is the mode of intrusion of each peak. It has been proposed (Dutton, 1884-85 and Hunt, 1937) that these bodies are remnants of feeder vents to an extension of the Mount Taylor lava flow capping Mesa Chivato and Mesa Prieta that has since been eroded away. The physical relationships of the

bodies with the surrounding sediments will indicate modes of intrusion of the bodies, which appear to be very unusual, in that the sediments immediately around each body seem undisturbed by the intrusive process. Of further significance is the scoriaceous basalt encountered at nearly every location, indicating phreatic stages associated with the intrusive processes.

Also of great significance in this study is the origin of the abundant ultramafic inclusions in the basalt masses. The inclusions' long diameters vary in length from less than 1 mm to 1/2 m. In the lower peak of Cerro Negro a wall of olivine-rich inclusions enclosed in a basalt matrix is exposed on the east side of the body. These inclusions are sub-rounded to angular, varying in size from three inches to 10 inches in length and covering an area of approximately 75 square feet. Also present are unusual xenocrysts of pyroxene incongruous with the majority of smaller pyroxene crystals in the groundmass of the basalt. Determination of the origin of these mineral inclusions and the great number of rock inclusions associated with many of the igneous bodies is mandatory for a complete inspection and interpretation of the origin, mode of intrusion, and original mineralogy of the basaltic rocks composing these peaks.

Acknowledgments

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PETROLOGY

General Petrography

In hand specimen the rocks from every location have the same fundamental appearance in that they are all dark, aphanitic, and dense. No mineral grains are distinguishable even with the aid of a hand lens, and a sample from bodies as widely separated in distance as Seboyeta Peak and Cabezon Peak are indistinguishable from one another in hand specimen. The only megascopically identifiable minerals are those encountered in the inclusions which are discussed under a separate heading. The only megascopically observed difference in the rocks at each location is in the effects of weathering, which are not consistent even in a single body. The majority of the basalts become reddish-brown on weathered surfaces, though some are whitish, and others demonstrate a spotty white with a background of darker coloring. No distinct mineralogical difference could be correlated with the apparent difference in weathering. These weathering variances are probably due to the length of exposure rather than mineralogic differences.

As in hand specimen, the thin section observation indicates no significant mineralogic differences between basalts from one body to the next. Generally, the textures

are intergranular. The feldspars are arranged in a felty texture, though trachytic textures are sometimes observed. Also, the rocks are generally microporphyrytic, the olivine in most cases being microglomeroporphyrytic. Glass, when observed, forms only a small portion of the total rock content in the thin sections and a hypohyaline texture is evident. The hypohyaline textures are most evident in the scoriaceous material, as would be expected, and where present in the massive basalt is found closely associated with locations having an abundance of scoria as exists at Seboyeta Peak.

Mineralogically, the rocks are composed of plagioclase (usually labradorite), pyroxene, usually augite, magnetite-ilmenite, and olivine. The mineral showing the least amount of regularity in abundance and mode of occurrence is olivine (Pl. 1 and 2).

PETROGRAPHY OF INDIVIDUAL PEAKS

Cabezon Peak

Cabezon Peak, located in the extreme northeast corner of the area, is the largest and most prominent feature in the field of igneous bodies, attaining an elevation of 7,785 feet at its crest (Fig. 1). The relief is approximately 2,100 feet. The nearly cylindrical body of Cabezon, having a mean diameter in excess of 1,500 feet, rises vertically from the top of the talus slopes. Cabezon exhibits well defined, regular columnar jointing which flares noticeably at its base (Pl. 3). The columns of basalt are six to eight inches in diameter. The body is macroscopically homogeneous in composition and texture. Numerous xenocrysts of olivine and pyroxene are noticeable in the dense, fine-grained basalt. The xenocrysts rarely exceed one quarter inch in length. Cabezon is capped with scoriaceous material, some of which may be found in the talus accumulations at the base of the peak. There is also a noticeable color difference between the scoriaceous cap and the underlying dense basalt.

The sediments surrounding Cabezon area part of the Mesaverde Formation and exhibit no signs of deformation by the magma intrusion. No signs of hydrothermal alteration are

present. Bleaching and secondary mineralization are absent. Also absent are inclusions of sedimentary material in the basalt forming the peak and in the basaltic material forming the talus slopes. Approximately one quarter mile to the west from the base of the talus are two isolated accumulations of basaltic material. These accumulations are on moderate slopes and are built up 1 to 2 feet above the surrounding sediment slumps. These unusual accumulations of basaltic debris are thought to be the result of shallow and small dikes or plugs intimately associated with the larger Cabezon intrusion. The basaltic material at these localities has the same appearance as the basaltic material forming Cabezon.

The basalt forming Cabezon is relatively homogeneous microscopically and contains olivine, augite, aegirine, labradorite, and titanomagnetite. Secondary mineralization in vesicles is present as chalcedony and a zeolite, probably stilbite, in small quantities. Chlorophaeite and iddingsite are also present as alterations of olivine.

The texture is intergranular and microporphyrytic. The basalt has a felty texture with no signs of preferred orientation. There is evidence in the plagioclase of two growth periods. The majority of the feldspar grains are less than 0.2 mm in length; a small number of the grains are

Plate 1. Elongated olivine phenocryst in fine-grained groundmass (x100).

Plate 2. Rounded olivine grains dispersed in groundmass (x100).

0.4 to 1 mm in length. Also, the plagioclase becomes more sodic on the rims of the grains, though the zoning is not distinct in most cases. Plagioclase constitutes approximately 30 percent of the basalt.

Augite is present as small grains within the groundmass and is often inconspicuous due to its small grain size and uniform distribution. The augite makes up approximately 30 percent of the basalt. Locally, the augite is present as a pseudomorph after olivine and contains grains of olivine and magnetite. Seemingly the augite has replaced the olivine in such instances. Augite does not occur as microphenocrysts.

The olivine is present both as single grains and as crystal aggregates composing 25 percent of the basalt. The single crystals of olivine are generally small and evenly distributed throughout the groundmass. The crystal aggregates are microporphyrytic, and locally alteration is present along the boundaries of the smaller crystals. No mineral lineations are present around the olivine grains to indicate that the grains were moved or forced through the magma during its crystallization. Occasional grains of olivine have been altered to antigorite, which rims or completely replaces the olivine. Antigorite infrequently occurs isolated in the groundmass.

The opaque minerals exist as small grains evenly dispersed throughout the groundmass in a quantity of approximately 10 percent. The opaque minerals are not in close association with either pyroxene pseudomorphs after olivine or pyroxene-rimmed olivine grains. Locally, opaque grains surround minute grains of the other minerals present in the groundmass. This is not a prevalent occurrence, however.

Plate 3. Aerial photograph of Cabezon Peak, looking south.

Plate 4. Aerial photograph of Cerro Cochino illustrating dike-like character of peak. View, looking south.

Cerro Cochino

Cerro Cochino is in the northeastern area of the igneous field 3 1/2 miles due south of Cabezon Peak (Fig. 1). The peak attains an elevation of 7,070 feet, a great deal less than that of Cabezon but nearly equal to that of Cerro de Guadalupe, which is approximately 3 miles to the west and north of Cerro Cochino. Cerro Cochino has a stronger resemblance to a dike than to a cylindrical plug (Pl. 4). The peak trends N.32°E. and is less than 1,000 feet long. The body is oval shaped, wide in the middle and tapering at each end, the maximum thickness being 500 feet at the base. The side walls of Cochino slant outward from the vertical, forming a ridge along its top 20 to 30 feet wide. Well defined columnar joints are present on all sides of the body and plunge to the south a few degrees. Cerro Cochino may be easily climbed from the north side which slopes down to ground level. A large talus accumulation is present below the west face in a small depression. Elsewhere the talus accumulates adjacent to the exposed base but is widely dispersed on the surrounding slopes with little significant concentration. Viewed from a distance, Cerro Cochino resembles a fin pointing northeast.

No scoriaceous basalt was found in the talus or on

the peak summit. Vesicular basalt was present, however, particularly within the central portion of the peak near the southern tip (Pl. 5). The vesicles are filled with a spherulitic white mineral identified in thin section as stilbite and calcite. Calcite also occurs independent of the stilbite in the groundmass of the vesicular basalt. The highly vesicular basalt is fragile and highly susceptible to weathering. Outward from the central vesicular area, the vesicle density decreases, but vesicles are present in small amounts in the denser basalt exhibiting columnar jointing near Cochino's summit.

The sediments surrounding Cerro Cochino are the same as found elsewhere in the field. As at Cabezon, no signs of deformation were observed. Also, no inclusions of sedimentary material or large xenocrysts of olivine-pyroxene were found at this locality. In three distinct localities 300 to 400 feet to the west of the base were rounded knolls 10 to 20 feet above the mean ground level. The knolls are approximately 100 feet in diameter and are located in a semicircle along the western side of the peak approximately 1,000 feet apart. Each of these knolls has an accumulation of coarse basaltic material on its crest, probably originating from shallow depth and indicative of smaller domal features

Plate 5. Highly vesicular core of Cerro Cochino.

Plate 6. West side of Cerro de Guadalupe (Note faint banding in zone above sediments).

associated with the main Cerro Cochino intrusion but presently unexposed by erosion.

The Cerro Cochino basalt consists of two main types: the more dense columnarly jointed basalt and the vesicular basalt of the peak's inner portion. The basalt types have essentially the same mineralogy, consisting of olivine, augite, labradorite, and titanomagnetite. The significant difference between the two basalts is in the textures. The dense basalt is trachytic intergranular whereas the vesicular basalt is hypohyaline and fragmental. Also, the vesicular basalt has a higher percentage of magnetite as finely disseminated grains in the groundmass. Both basalt types are microporphyritic and microglomeroporphyritic.

The olivine occurs as microporphyries and microglomeroporphyries. In many instances the olivine appears to be broken fragments of larger crystals and is subhedral in all occurrences. These features are most evident in the larger crystals. Olivine is, however, roughly disseminated throughout the groundmass of the basalt, totalling 20 percent of the rock. The percentage of olivine present in the vesicular basalt is less.

The augite is present both as small crystals in the groundmass and as microphenocrysts. Locally the augite is

closely associated with magnetite grains, either within the grains or located against the crystals edges. The larger crystals of augite have their longer directions parallel to the flow direction, indicated by the feldspars. The smaller, short grains in the groundmass are generally subhedral. These smaller grains are not as closely aligned as the larger augite grains. The total augite content of the basalt is nearly 30 percent.

The plagioclase exhibits a trachytic to pilotaxitic structure in the groundmass and constitutes nearly 40 percent of the basalt. The labradorite is polysynthetically twinned and exhibits slight zonation in the larger grains. The layers are too thin for accurate optical compositional determination. Two generations of feldspar growth are present, indicated by a majority of smaller grains in the groundmass, often clustering parallel to the larger feldspar grains. The length of the feldspar ranges from 0.15 mm in the smaller grains to 0.6 mm in the larger grains.

The opaque grains present are generally 0.5 mm or less in width, although much larger grains are present. Many larger grains contain minute anhedral grains of plagioclase and pyroxene or partly enclose crystal terminations of these grains. In the more vesicular basalt the opaques form a

higher percentage of the rock and are finely disseminated in the groundmass, whereas in the more dense basalt the magnetite is less than 10 percent of the total minerals and is more randomly distributed in the groundmass.

The distinct differences in sizes of the augite, plagioclase, and opaque grains strongly suggest two periods of mineral crystallization at Cerro Cochino. The basalt magma was probably intruded as a crystal mush, as indicated by the trachytic texture, and the smaller grains formed later, either during the late intrusive stages or after the magma experienced a period of quiescence following the major intrusion.

Cerro de Guadalupe

Cerro de Guadalupe is in the north-central part of the area. The peak is 3 miles south of Cabezon Peak and 3 miles northwest of Cerro Cochino (Fig. 1). Cerro de Guadalupe attains an elevation of 6,800 feet and is the most irregular body within the entire igneous field. The peak is composed of basaltic material, a portion of which exhibits no columnar jointing. The columnar jointing present is coarse on the south side but generally relatively fine and crudely tilted in a random manner. On the north face a dike of basaltic rock containing a large amount of disseminated olivine cuts obliquely and horizontally through the jointed basaltic host rock (Fig. 2). Also present in the host rock on the north face are large xenoliths of websterite. These xenoliths are ellipsoidal in shape with their major axis ranging from 3 to 8 inches in length. Frequently these xenoliths can be plucked by hand from the basalt due to weathering, though the minerals are intensely oxidized and stained.

The most striking and interesting feature of the peak's south side is a series of dikes radiating away from the base. The dikes are 3 feet wide and the longest extends for a distance of 1,500 feet to the southwest before it

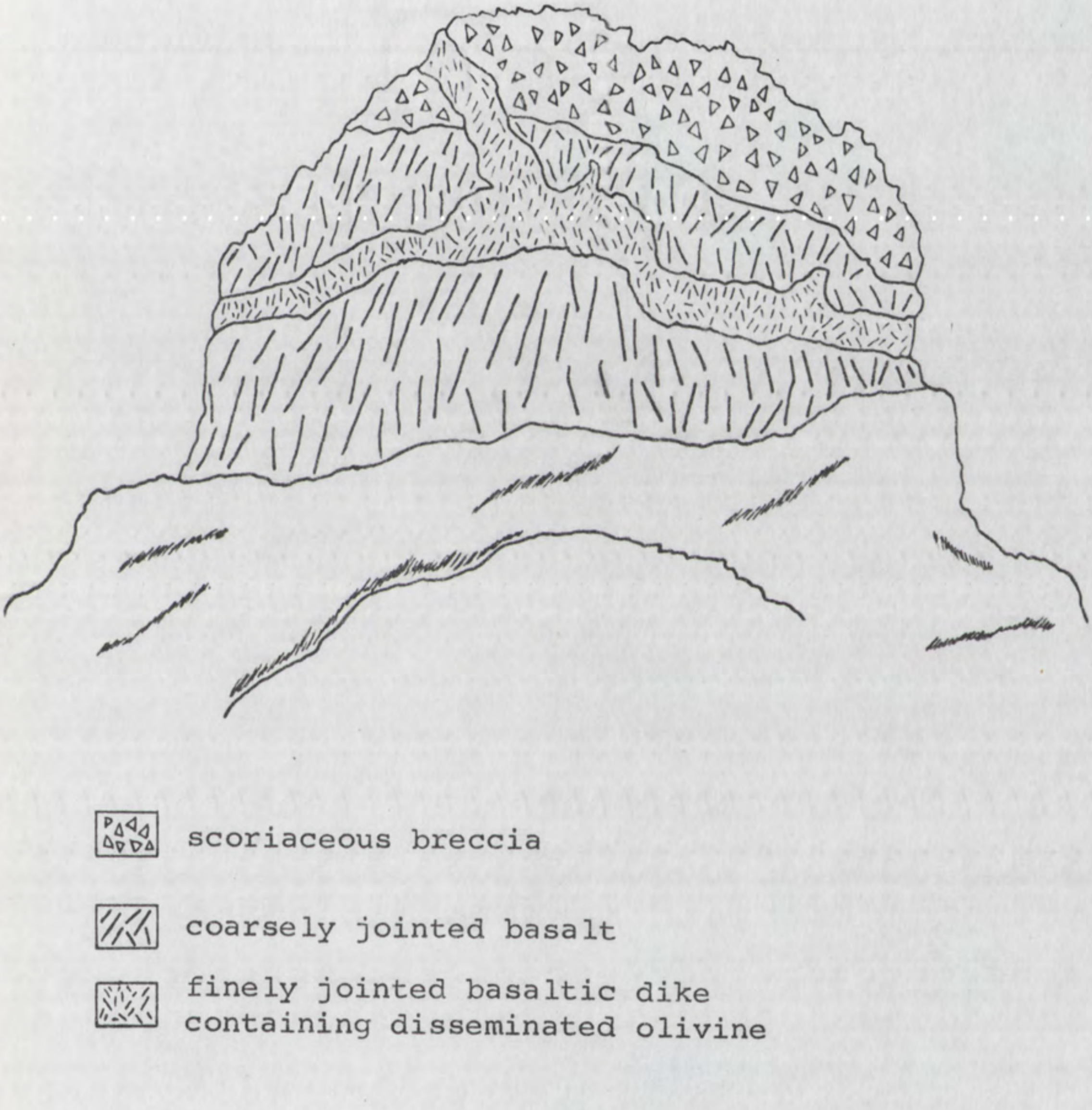


Figure 2. North side of Cerro de Guadalupe.

disappears beneath the sediment cover. The dikes are composed of very dark, dense basalt and demonstrate crude columnar jointing perpendicular to the sides of the dikes. The dikes protrude only 2 or 3 feet above the surrounding sediments which appear undeformed by the intrusion. Horizontally bedded sediments are visible in outcrop 10 to 20 feet from the dikes in places. Infrequent pieces of noticeably bleached and baked sandstone are present in the dikes as well as in the eastern side of the peak.

The eastern face of Cerro de Guadalupe has a great deal of scoriaceous and brecciated material in its central portion. The matrix of this material is fine-grained, vesicular basalt with small angular fragments of basaltic and sedimentary material enclosed. Olivine is also present as small grains in the scoriaceous material.

Viewed from a distance the west face appears to have roughly parallel bands, caused by color variations in the rock that strongly resemble bedding planes (Pl. 6). It is possible that this feature is caused by partial assimilation in place of the sedimentary material. Similar features are also present at other localities and will be described later in the thesis. The top of the peak is capped by scoriaceous material thought to be similar to that found on the east face

of the peak. The peak's crest as well as the western face are inaccessible for closer and more detailed examination.

Olivine, enstatite, augite, hypersthene, calcic labradorite, and opaques are present in the basalt forming Cerro de Guadalupe. Also present in a significant amount are calcite and chalcedony, probably of secondary origin. The relative proportion of the minerals present vary from sample to sample.

The texture of the basalt forming Cerro de Guadalupe varies from microporphyritic felty to microporphyritic trachytic. Also, the glass content varies and some samples are intersertal, whereas others are intergranular. Here as in other localities, the olivine is often microglomeroporphyritic. Frequently opaques and glass are poikilitically included in the pyroxene grains. The groundmass is very fine grained in all instances.

Plagioclase grains are generally equidimensional and homogeneous in composition. The laths are broken at both ends as if they were crystalline before injection and violently disturbed during intrusion. The feldspar composes 40 percent of the basalt.

Augite is the dominant pyroxene within the groundmass. Rare enstatite is present as individual isolated grains

and is chiefly present as exsolution lamellae of the clinopyroxene augite. Hypersthene occurs only within the large glomeroporphyries with olivine and is probably of foreign origin (i.e., an inclusion). The total pyroxene present in the basalt is 25 percent, including the large xenocrysts.

Olivine occurs as rounded crystals in the groundmass and within the xenocrysts with hypersthene and augite. The rounded olivine grains in the groundmass display no alteration to pyroxene. Locally the olivine grains are surrounded on three sides by feldspar laths sub-parallel to the grain edges. The olivine glomeroporphyries are generally smaller than observed in other localities when they are the sole constituents of these features. Olivine constitutes 25 percent of the basalt. Antigorite is infrequently observed internally within the olivine grains. Iddingsite is sporadically associated with the olivine grains.

Chalcedony and calcite are both considered secondary minerals. The chalcedony rims vesicles and commonly fills a cavity with a wormy intergrowth. Calcite is either isolated as amygdules or associated with the xenocrysts where they have weathered. Chlorophaeite is present in the groundmass as alteration of the glass and often rims vesicles within the rock matrix. The secondary minerals combined with the

glass constitute from 8 to 10 percent of the basalt at Cerro de Guadalupe.

Great Neck Peak

Great Neck Peak is in the central part of the area, approximately 4 miles northeast of Cerro de Jacabo (Fig. 1). This peak, as well as the peaks of Cerro de Santa Rosa and Cerro de Jacabo, have a variety of names. The two names most widely used are Great Neck Peak and Cerro de Nuestra Senora. Great Neck Peak will be used for the purposes of this discussion. The peak is the largest body in the southern part of the area, attaining an elevation of 7,313 feet. It is roughly cylindrical in shape. The diameter of the peak at its base is approximately 800 feet. Great Neck Peak is surrounded by steeply sloping hills that are covered with basaltic debris. Boulders with diameters up to 3 feet in length are present in a dry wash 1 mile to the northwest of the peak. Great Neck Peak is composed of dark, dense basalt that displays well defined columnar jointing. The joints are coarse to medium sized and the most regular in the field with the exception of Cabezon. However, the east face does exhibit slight local disturbances incongruous with the generally regular jointing. The jointing system does flare evenly at the peak's base on all sides. The top of the peak is capped with a large mass of scoriaceous and brecciated material.

No xenoliths of country rock are present in the dense

basalt forming the main body of the peak. And, again, no sediment deformation is present. No contacts between the sediments and the igneous body are exposed, however, since a large talus accumulation surrounds the peak and spreads outward for several hundred feet from the base. The south face of Great Neck Peak appears to have roughly horizontal parallel bands caused by color variation in the rock that strongly resemble the bedding planes of sedimentary rocks. This face is similar in appearance to the west face of Cerro de Guadalupe and like Guadalupe, is inaccessible for closer and more detailed observation due to the steepness of the surroundings. This feature abuts against the dense basaltic mass. To the north of the main peak are a number of minor bodies with accumulations of talus similar to corresponding features found at other localities in the field and thought to be related to the main peaks.

A very unusual outcrop is present three quarters of a mile to the west of the main peak and near the windmill at Lagunitas Well. The outcrop is in a small valley about 40 feet above the main valley floor (Fig. 3). The outcrop consists of a conglomerate overlain by scoriaceous basalt. In its thickest part there are 10 feet of conglomerate and 15 feet of scoriaceous basalt. The conglomerate and scoriaceous basalt

thin as a unit to the east for approximately 300 feet, where they both disappear. The conglomerate possesses ill-defined stratification in its thick portion, but the stratification becomes more pronounced to the east, where the unit thins. Throughout, the scoriaceous basalt remains massive even though it thins to the east and loses its surface expression before the underlying conglomerate disappears. No definite contact between this unit and the Mancos Shale is present, as the entire area is covered with sediment slumping and debris from the main peak. The western edge of the outcrop does not possess any features within each unit to measure attitudes, though the contact between the two lithologies dips 22° to the northeast. The eastern edge of the body has a strike of N.85°E. and dips 22° to the northwest. Digging in several localities away from the edge of the outcrop produced a poorly preserved clay with pisolities of an unidentifiable material, but no conglomerate similar to that present in the outcrop.

The conglomerate pebbles are basaltic and are cemented by a clay matrix. The basaltic pebbles are composed of plagioclase laths, rare pyroxene, vesicles filled with analcime, and a glassy matrix. The matrix material contains a clay mineral, fragmental quartz grains, untwinned plagioclase, and rare grains of pyroxene. Judging from the

direction of thinning and the decrease in particle size within the conglomerate, the source direction was in the west, probably not far removed from the position of the present outcrop. This eliminates the possibility that the source is Great Neck, since the peak lies to the east of the outcrop and is too distant to have been its source. It is further suggested that the attitudes of the outcrop are due to unexposed intrusions associated with Great Neck.

The basalt forming the main body of Great Neck Peak is similar to that present in other localities of the area. The texture is intergranular trachytic overall and intergranular felty locally. Also, the basalt is microporphyritic. Small amounts of glass are rarely present in the groundmass but never constitute more than 2 percent of the rock. In addition, olivine, augite, plagioclase, and opaque minerals are present.

The olivine occurs exclusively as microphenocrysts and is not present as small grains in the groundmass. Commonly the olivine grains are fractured, and they exhibit elongation parallel to the flow structure demonstrated in the groundmass. Rare grains of olivine are altered to antigorite and iddingsite along fractures and some grain edges. Small aggregates of pyroxene grains frequently surround the

olivine grains. The olivine constitutes 20 percent of the rock.

Augite constitutes 30 percent of the rock. Individual grains of augite do not occur as microphenocrysts in the basalt. Occasional aggregates of augite are present, randomly dispersed in the groundmass. Generally the augite grains in the groundmass are only 0.5 mm in diameter, much smaller than the plagioclase laths. Augite occurs between the plagioclase laths.

The plagioclase (labradorite) is generally well twinned, though crystal edges are often indistinct. Some plagioclases are normally zoned. Although the zoned crystals are too small for accurate compositional determination, the rims appear to be more sodic than the cores. Plagioclase constitutes 40 percent of the basalt.

The opaque minerals constitute 7 to 10 percent of the rock. Generally the opaque grains are equidimensional and randomly dispersed in the groundmass. Little or no accumulation of opaque grains are present in the immediate areas surrounding the pyroxene aggregates where isolated or associated with the olivine grains. Also, the size of the opaque grains is uniform throughout the basalt (0.03 mm). Calcite is present rarely and usually is associated with the olivine grains. Calcite, when present constitutes from 2 to 3 percent.

Cerro de Santa Rosa

Cerro de Santa Rosa is located in the south central part of the area, approximately 1 1/2 miles due south of Cerro de Jacabo and approximately 1 mile due north of Cerro Chato (Fig. 1). The peak is composed of coarsely jointed columnar basalt and attains an elevation of 7,165 feet at its crest. The peak is semicircular with its long axis east-west. The main body of the peak is approximately 500 feet long and 250 feet wide at its broadest point. Cerro de Santa Rosa possesses well defined columnar jointing in the upper one fourth of the body, but the lower portion of the mass has a suggestion of typical flaring though the columnar jointing is erratic and ill defined in general (Pl. 7). No large cap of scoriaceous material exists on Santa Rosa's crest, though a good deal of scoriaceous and brecciated material is present in the debris surrounding the peak. This material contains secondary minerals (stilbite, chalcedony, and calcite) and a few grains of olivine. Along the east face of the peak up to 20 feet above the level of the base, intensely weathered basaltic breccia is present. The breccia contains small, angular xenoliths of shale and sandstone. This breccia contains secondary minerals occurring as implanted globules within irregularities in the breccia.

The base of Cerro de Santa Rosa is surrounded by coarse basaltic talus. The talus apron slopes steeply away from the peak's base and does not extend laterally as far as most talus aprons in the area. Small bodies possessing columnar jointing are partially exposed within the talus slopes and in the immediately surrounding area. The joints are curved slightly and are tilted from the vertical. North of Cerro de Santa Rosa along the south sides of small hills 50 to 100 feet away are unusual talus expressions of hidden intrusions which may be directly related to the main body of the intrusion.

The basalt forming Cerro de Santa Rosa is essentially homogeneous in appearance and commonly contains inclusions of olivine material. Also present as inclusions in the basalt are dark, vitreous xenocrysts completely lacking cleavage. These inclusions are similar to the ones found in the dikes at Seboyeta and identified as hypersthene-augite. An exceptional and uncommon inclusion (lherzolite) was discovered here, consisting of augite, hypersthene, olivine, and metallic minerals identified by Mr. George Conrad, using the microprobe, as pyrrhotite, chalcopyrite, ilmenite, chromite, and magnetite.

The rock forming Cerro de Santa Rosa is similar to

the basalt at other localities in the area. Augite, olivine, plagioclase, and opaque minerals, probably titanomagnetite, constitute the basalt. The texture ranges from intergranular felty to intergranular trachytic. The basalt is also microporphyritic containing phenocrysts of olivine and augite. The olivine occurs as isolated anhedral grains evenly dispersed in the groundmass as microphenocrysts. The olivine is unaltered. It has no reaction rims but is surrounded by feldspar laths. Fifteen percent of the rock is olivine.

Augite microphenocrysts are generally anhedral. Magnetite is seldom included in the augite grains or is present around the borders of augite crystals. Infrequent oval aggregates of stubby augite crystals are commonly associated with small amounts of magnetite. These aggregates could possibly be the result of augite replacement of olivine though no olivine remains within the crystal aggregates. Augite also constitutes a large amount of the groundmass as small, indistinct crystals. The augite constitutes from 25 to 30 percent of the basalt.

Plagioclase present is calcic andesite or sodic labradorite as is present in a few other localities, notably, Cerro de Jacabo, Cerro Chato, and Seboyeta Peak. The laths are generally well formed, though fragmental laths are rarely

present in the groundmass. The twinning in the laths is distinct even though incomplete twin lamellae are not uncommon. No zoning is present in the plagioclase. In certain instances two sizes of laths are present, though the size ranges are not great. Both sizes of feldspar have the same composition. The plagioclase constitutes from 40 to 50 percent of the rock.

Opaque minerals constitute from 8 to 10 percent of the groundmass material. These minerals are generally 0.2 mm across or less. Glass is present rarely and never constitutes more than 3 percent of the rock.

The secondary minerals discussed earlier are confined to occurrences in the brecciated and scoriaceous material. No secondary mineralization is present in the dense basalt. Where present, the secondary minerals of stilbite, calcite, and chalcedony constitute from 5 to 8 percent of the rock.

Plate 7. Cerro de Santa Rosa, looking east.

Plate 8. Cerro Jacabo, looking east.

Cerro de Jacabo

Cerro de Jacabo is in the south-central part of the area approximately 1 1/2 miles due north of Cerro de Santa Rosa (Fig. 1). Cerro de Jacabo, Cerro de Santa Rosa and Cerro de Nuestra Senora are often called Cerros de Nuestra Senora de la Luz de Las Lagunitas (Peaks of Our Lady of the Lakelights). These peaks are also called Los Cerros de Nuestra Senora and the twin peaks of Jacabo and Santa Rosa are separately called Santa Rosa Peaks while Great Neck is referred to as Cerro de las Lagunitas as well as Cerro de Nuestra Senora. These names originate from the fact that they are within a land grant named Nuestra Senora de la Luz de las Lagunitas. These names vary from one publication to another. The names adopted here are taken from 15-minute quadrangle maps published by the U. S. Geological Survey, and Hunt's paper (1937).

Cerro de Jacabo is the larger of the twin peaks, attaining an elevation of 7,437 feet and being approximately 800 feet in diameter at its broadest point. The basalt forming the peak displays medium to fine jointing similar to that present at Cerro Vacio (Pl. 8). The upper portion of Cerro de Jacabo's jointing pattern is directionally erratic, tending toward the horizontal. Regular flaring of the

jointing pattern is present around the exposed base, however. As in many other locations in the area, the crest of Jacabo is capped with scoriaceous and brecciated material. Occasional large boulders of brecciated material standing 20 feet high are present at considerable distances from the base of the peak. The base of the peak is surrounded by an apron of talus. Cerro de Jacabo is essentially cylindrical, though slight elongation to the south and northeast are indicated in the lower portion of the body.

Outlying smaller plugs are present at Cerro de Jacabo as at many other locations. These smaller bodies are generally much less than 100 feet in diameter and possess well defined jointing, though it is often erratic. A close inspection of the immediately surrounding area revealed no indications that these small bodies are enlargements of dikes radiating from the main body. It is believed that much of the undulating topographic features around Cerro de Jacabo are the result of similar intrusions that are as yet unexposed.

No inclusions of country rock are present in the basaltic sidewalls of Cerro de Jacabo, though a great deal of country rock is present in the scoriaceous breccia. These inclusions are indicated by a lighter color than the surrounding matrix. Present in the basalt at Jacabo are occasional

xenoliths of lherzolite. There does not exist a preponderance of the inclusion, however. Often angular cavities containing a few oxidized grains of pyroxene or olivine are found in the talus. Fresh samples are generally difficult to obtain.

There are two basalts at Cerro de Jacabo. The petrography of the first basalt forming the peak is similar to the basalt found at the other localities in the area. In hand specimen the basalt is dense and black. Close examination of a fresh surface reveals numerous small unidentifiable crystals which give the rock a luster not seen in other basalts. Thin section examination reveals that these small crystals are primarily olivine and generally much larger than the individual olivine crystals present at other localities. The texture of this Cerro de Jacabo basalt is fine-grained felty to fine-grained trachytic. The olivine and augite both occur as microphenocrysts, generally 0.3 mm in diameter. Other minerals present are sodic labradorite and an opaque, probably titanomagnetite.

Olivine is abundant at Cerro de Jacabo composing 25 percent of the basalt. The grains of olivine are generally anhedral and rounded. The majority of microphenocrysts are olivine grains. The unusual property of the olivine present is that it exists as individual grains rather

than as aggregates of three or more grains. Where the texture is slightly trachytic, the feldspar laths display a flow structure around the olivine grains giving the olivine an appearance of augen found in augen gneiss. A few olivine grains are surrounded by augite, though this occurrence is rare and only a small amount of the olivine remains. Very little of the groundmass material is olivine; it occurs almost exclusively as microphenocrysts.

The augite present occurs chiefly as groundmass material. The few microphenocrysts of augite present possess wavy extinction and lack euhedral outlines. Edges of the augite microphenocrysts are undulating and the crystals of the augite are elongated. Also, most of the large grains contain opaque inclusions and laths of plagioclase which occasionally display well defined twinning. Infrequent augite grains rim small olivine crystals and contain both plagioclase laths and opaque grains. The augite grains in the groundmass are minute crystals between plagioclase grains. Augite constitutes 15 percent of the rock.

The plagioclase occurs as laths in the groundmass. The twins are generally well defined and extinction is sharp. No zoning is observed in the majority of the grains and the composition varies only slightly from one grain to another.

The plagioclase constitutes 50 percent of the rock.

The opaque minerals, constituting 5 to 8 percent of the mineralogy, are evenly dispersed throughout the groundmass. Local concentrations of opaque grains do occur around the edges of some of the larger augite grains and within the augite crystals. The opaque grains are generally equidimensional.

The second type of basalt present at Cerro de Jacabo departs markedly from the type previously discussed. The basalt weathers unevenly on its surface and is severely fractured. This basalt is a dense, black rock containing glass and in continuity along the peak face with the holocrystalline basalt. The glass constitutes 45 percent of the rock; augite, olivine, plagioclase, and opaques make up the remainder. The mineral grains present are generally fragmental, with rough edges and terminations. The plagioclase has indistinct boundaries and often displays no twinning. Fifteen percent of the rock is plagioclase. Olivine and augite occur as separate grains and together constitute 30 percent of the rock. Two sizes of opaque grains are present in the groundmass; the larger grains have random distribution whereas the smaller, almost indiscernable grains generally aggregate in restricted areas giving the entire mass a dark

appearance in unpolarized transmitted light. Opaque minerals constitute 10 percent of the basalt.

Cerro Chato

Cerro Chato is located in the south-central part of the area approximately 2 miles north-northeast of Cerro Vacio and within easy walking distance from the old Lee Evan's ranch (Fig. 1). The peak is relatively small, being approximately 500 feet wide and 1,000 feet in its longest direction. Cerro Chato attains an elevation of 6,916 feet and is practically level across its summit (Pl. 9). The elongation of Cerro Chato is to the northwest, perpendicular to the elongation directions of Cerro Vacio and Cochino, which are to the northeast. The peak is composed of dense basaltic rock that demonstrates well defined, medium-sized columnar jointing. The jointing pattern is irregular, particularly in the upper portion of the body where it is tilted at an angle of 30° from the vertical. Cerro Chato is surrounded at its base with coarse basaltic talus and possesses no visible contacts between the sedimentary country rock and the peak sides. Only small amounts of scoriaceous basaltic material are present in the talus, though the cap of Cerro Chato appears to be composed of scoria and breccia. No inclusions of country rock are present in the faces of the peak. However, numerous xenocrysts of dark to light green

minerals are present, ranging in length from 5 to 20 mm. Also present are minor amounts of white secondary minerals occurring as vesicle and cavity fillings and identified as stilbite and calcite. The basalt forming Cerro Chato is essentially homogeneous around the base.

In the area immediately to the south of Cerro Chato is a small body protruding approximately 5 feet above the talus accumulation. This small body possesses well defined medium-sized columnar jointing tilted at an angle of 15° from the horizontal. The basalt forming this small body is the same as the basalt in the main peak. Present in the small body are numerous angular xenocrysts of olivine-pyroxene, the same as present in the basaltic mass of Cerro Chato.

The minerals forming the basalt at Cerro Chato are olivine, augite, labradorite, and an opaque, probably titanomagnetite. The texture is intergranular felty to intergranular trachytic. The trachytic structure is localized and slight flow structure is most evident around grains of olivine. The basalt is also microporphyritic with respect to olivine and augite. Small amounts of calcite are present, all occurrences closely associated with the xenocrysts. The calcite is coarsely crystalline and often encloses plagioclase and augite grains.

Twenty percent of the rock is olivine which generally occurs as small angular to subrounded microphenocrysts. Some of the olivine displays twinning and internal fracture. Alteration along fracture lines is absent. Rimming of the olivine by pyroxene is also absent except in rare grains, and where present is minor.

Few microphenocrysts of augite are present. The greatest amount of the augite present is in the groundmass between plagioclase laths. The augite is subhedral and generally equidimensional, particularly in the groundmass. Numerous cloudy and indistinct areas are present in the groundmass, consisting of aggregates of stubby augite grains, plagioclase laths, and opaques. These aggregates are probably complete replacements of olivine. Augite constitutes 30 percent.

The plagioclase occurs as laths in the groundmass. The laths usually do not display well defined twinning lamellae or sharp extinction. Commonly the extinction is wavy and moves across the surface of the grain to the outside edge of the lath. The majority of the plagioclase grains are lath-like and possess sharp outlines. Other grains occur as relatively large crystals often enclosing some of the smaller plagioclase laths. These larger grains are untwinned and

display no wavy extinction. Plagioclase constitutes 40 percent of the rock.

The opaque grains are evenly dispersed throughout the groundmass and consist of small (0.01 mm) grains. Generally the opaques are equidimensional and all of the same size. Occasional larger grains ranging up to 0.1 mm in diameter are present, though their occurrence is rare. Opaque minerals constitute 8 to 10 percent of the rock. The secondary calcite present is localized in areas adjacent to or within xenocrysts. In no instance is the amount of the calcite present greater than 4 percent of the rock.

Plate 9. Cerro Chato (in right foreground), Cerro Jacabo (left), and Great Neck (in distant left). View looking north.

Plate 10. East face of Cerro Vacio.

Cerro Vacio

Cerro Vacio is located in the southwestern part of the area adjacent to the northeast corner of Valencia County, New Mexico (Fig. 1). The peak is approximately 2 miles south-southwest of Cerro Chato, both being within easy walking distance of the old Lee Evan's ranch. Cerro Vacio is not an impressively large peak in volume, though it attains an elevation of 7,915 feet and is higher than Cabezon, though Vacio's relief is not as great. The main body of Cerro Vacio is only a little over 200 feet wide at its thickest point. The most interesting feature about the peak is its elongation closely parallel to that of Cerro Cochino in the northeastern part of the area. Like Cerro Cochino, Cerro Vacio is less than 1,000 feet in length. Vacio, however, does not slope down to the surface of the surrounding sediments but has steep faces all around (Pl. 10). Talus accumulations surround the base of the peak but are not as coarse as most of that surrounding the other peaks in the area. This is probably due to the nature of the jointing at Cerro Vacio, which in certain instances is quite thin, resembling the parting present in slate. Fine jointing commonly is present abutting abruptly against coarser jointing patterns (Pl. 11). One set of joints may dip

sharply into another set or may even be flat lying with a vertical set of joints beneath. This manner of jointing suggests that there were several episodes of intrusion, each followed by a period of quiescence and cooling that would allow a joint system to develop. The jointing pattern flares at the base around the entire circumference of the peak.

No scoriaceous cap was noted overlying the basalt, nor was any scoriaceous material observed in the immediate surrounding talus. Large fragments of scoriaceous basalt was discovered in dry washes one quarter mile southeast of Cerro Vacio. The head of these washes originates near the peak itself, suggesting Cerro Vacio is the source, though similar pieces of vesicular and massive basalt can be found in the surrounding area up to five miles away from any of the intrusive features. Inclusions of country rock are relatively scarce in the basalt at Cerro Vacio. For the most part, the pieces are small and fragmental. One interesting sandstone xenolith was discovered on the east face of the peak, approximately 100 feet above the base. The spherical xenolith of white sandstone measures approximately 1 foot in length and is surrounded by a glassy basaltic rim only one-half inch thick. No definite flow structure is present in

the area around the xenolith (Pl. 12). Also present in the massive basalt are angular fragments of olivine-pyroxene, generally less than 2 inches in length. Numerous angular cavities are apparent, resulting from the weathering of these xenocrysts and leaving only a few intensely weathered grains of olivine and reddish-brown oxide coatings in the nearly vacant cavities. Also present in significant amounts is a white mineral usually filling elongate cavities and having a spherulitic structure. The minerals have been identified as calcite and natrolite.

The mineralogy and texture of the basalt forming Cerro Vacio are similar to the other basalts found in this area except for the aegerine and aegerine-augite. Other minerals composing the basalt are olivine, augite, labradorite, and titanomagnetite. Texturally, the basalt ranges from intergranular felty to intergranular trachytic and is microporphyritic. Small amounts of isolated glass are present, though not in excess of 1 percent in any specimen.

The aegerine occurs as occasional small, anhedral grains in the groundmass and as alteration on the tips of augite grains. The predominant pyroxene is augite, occurring both as small grains in the groundmass and as micro-

Plate 11. Abutting of coarse and fine jointing at Cerro Vacio.

Plate 12. Sandstone xenolith in east face of Cerro Vacio.

phenocrysts 1 mm in length. Commonly the augite is associated with the olivine in microglomeroporphyries. Occasionally the augite has a mottled appearance and appears embayed around its edges. Some aegerine-augite borders isolated grains of olivine. The pyroxenes constitute 30 percent of the basalt.

The olivine present in the Cerro Vacio basalt commonly occurs as microglomeroporphyries associated with augite. Smaller grains of olivine are present in the groundmass, occasionally rimmed by pyroxene. The larger olivine grains are often surrounded by feldspars sub-parallel to the olivine crystal outlines whereas the pyroxene grains are parallel to the long direction of the feldspar laths in all instances and do not indicate discontinuity with the lineations of the groundmass material. The olivine constitutes 15 to 20 percent of the minerals present.

The plagioclase laths are closely packed, often abutting against one another. Often, too, the twinning is not well defined and the extinction is wavy within the grains. Numerous instances exist of several plagioclase laths coming together at a mutual point. Possibly each lath originated from this crystallization nucleus. These facts seem to indicate rapid crystallization of the feldspars,

which constitute 40 percent of the minerals present in the basalt.

The opaque minerals occur as small, isolated grains disseminated evenly throughout the groundmass. Most of the opaques are of similar size, though a few larger grains are present and commonly enclose minute crystals of plagioclase and pyroxene. Some pyroxene grains contain a small number of opaque grains. The opaque minerals constitute between 8 and 10 percent of the basalt at Cerro Vacio.

Cerro Negro

Cerro Negro is the most unusual and interesting basaltic body within the entire area. The peak is located on the extreme southeastern edge of Mesa Chivato, approximately 2 miles from the existing lava cap. Cerro Negro is 2 miles northeast of Seboyeta Peak and 2 3/4 miles northeast of the pueblo of Moquino, New Mexico (Fig. 1). Two basaltic bodies compose Cerro Negro and are separated by a distance of approximately 400 feet, the larger body being due north of the more complex, smaller peak (Pl. 13). The smaller peak has an elevation of 7,000 feet; the larger peak is 200 feet higher. Neither of these peaks possesses impressive height above the surrounding sediments, as they are located on the edge of Mesa Chivato. The larger peak is similar to the other peaks in the field. It is composed of homogeneous, dense basalt with small xenocrysts of olivine and displays well defined columnar jointing in the basalt. The upper set of the joints is nearly horizontal having a slightly convex bending in certain portions while in other instances the jointing patterns are irregularly slanted but more nearly vertical. The lower set of columnar joints are well defined and are nearly vertical, noticeably flaring at the base. This jointing pattern strongly suggests at least two and

Plate 13. The two peaks of Cerro Negro.
View looking north.

Plate 14. Erratic jointing patterns on southwest face of lower peak at Cerro Negro.

probably more episodes of intrusion followed by periods of quiescence and cooling allowing the jointing systems to develop.

Little columnar jointing is present in the smaller peak in its lower portion. The upper portion of the peak, however, does display some columnar jointing. The jointing is irregular and appears to have been severely disturbed. Also, the jointing is finer than that present in most other localities in the field and much finer than that of the larger peak at Cerro Negro (Pls. 14 and 15). Little scoriaceous material is present on the larger peak's crest or in the surrounding talus. Scoria and breccia does form a portion of the smaller peak's southeast face, however.

The southernmost peak, though smaller, presents more problems and intriguing relationships than any other body in the entire area. This peak is quite small, being only 100 feet in diameter and rising approximately 150 feet above the surrounding sediments. The south, east, and west faces of the smaller peak contain abundant xenoliths of sandstone and partially fused sediment (Pl. 16). In most instances the partially fused sediment retains well defined bedding, though it is commonly undulating. Parts of the xenolith are almost completely glassy, displaying alternating

Plate 15. Convex jointing in larger peak of Cerro Negro. (South face).

Plate 16. Breccia in lower peak of Cerro Negro. (Note sandstone xenoliths).

light and dark bands. The only identifiable minerals in the glassy portions are quartz grains and rare grains of altered feldspar, both occurring as angular grains, commonly severely fractured. The xenoliths of country rock in the east face consist of angular pieces (one inch long) of indeterminate original minerals. These xenoliths are evident in hand specimen as light colored areas surrounded by dark basalt. However, the xenolith boundaries are diffuse in thin section, indicating that they have been incorporated and invaded by glassy basalt that contained microphenocrysts of olivine and augite and occasional laths of mottled feldspar.

Inclusions of olivine-pyroxene are by far the most abundant. Each face of the smaller peak is studded with inclusions of this type, some as long as 10 inches and 6 to 8 inches wide. One large inclusion 15 inches long and 10 inches in diameter was discovered on the western talus slope (Pl. 17). The inclusions are of two main types. One type, consisting of olivine, augite, and hypersthene, (lherzolite), is in greatest abundance and forms a solid wall "cemented" by basalt on the eastern face (Pl. 18). This accumulation covers an area of approximately 75 square feet. The second type of inclusion consists of deep green augite and hypersthene, approximately in a 50-50 ratio (websterite). This

Plate 17. Large lherzolite xenolith from Cerro Negro.

Plate 18. Wall of "cemented" lherzolite, east side of lower peak, Cerro Negro.

type of inclusion is rare in comparison with lherzolite. One sample contains these two in contact (Pl. 19). Also present are a number of small dikes composed almost entirely of lherzolite contained in a basaltic groundmass.

The basalt forming the peaks is similar to that forming the other peaks. The texture is intergranular felty with microphenocrysts of olivine and augite. Also present are plagioclase, and opaque minerals. All the mineral grains are essentially euhedral, with the exception of the opaques, which are irregular.

Most of the olivine is altered around its edges, and commonly grains are present with antigorite cutting them. The olivine constitutes 20 percent of the total minerals present. Augite is present in an abundance equal to that of olivine. Grains of each of these minerals are evenly dispersed throughout the groundmass, though the augite also occurs as small grains between plagioclase laths. The plagioclase laths have indefinite edges and zoning of an indeterminable type. Twinning is generally well defined. The feldspar constitutes 45 percent of the basalt. The opaque minerals are evenly dispersed throughout the groundmass and are equidimensional, constituting 5 to 8 percent of the minerals present. No inclusions of opaque minerals are

Plate 19. Websterite and lherzolite in contact, east side of lower peak, Cerro Negro.

Plate 20. Small domal basaltic bodies protruding from talus between the two peaks of Cerro Negro.

present in the augite grains. Also present are calcite and chalcedony. The chalcedony is minor and occurs in cavity linings and with the calcite. Numerous vesicles within the basalt are filled with coarsely crystalline calcite. The two secondary minerals constitute 5 percent of the rock at Cerro Negro.

In the area immediately surrounding the two peaks of Cerro Negro are numerous small plugs, often marked by accumulations of basaltic material. These small bodies are dense, fine-grained basalt and contain few xenoliths of either lherzolite or websterite incorporated in their basalt (Pl. 20). Generally these bodies have well defined, medium-sized, columnar joints that are vertical or slightly inclined. Each of these bodies is thought to be a small subsidiary intrusion associated with the larger intrusions that are responsible for the main peaks at Cerro Negro.

Seboyeta Peak

Seboyeta Peak is in the extreme southwestern part of the area. The peak is approximately 1 1/2 miles southeast of the pueblo of Seboyeta and immediately accessible by New Mexico Highway 279 between Laguna and Seboyeta, New Mexico (Fig. 1). Seboyeta Peak is distinct from any of the other peaks within this field in that the main body is formed almost entirely of basaltic scoria and breccia. The core of the main peak has the only massive basalt present (Pl. 21). The scoriaceous and breccia material forms an envelope enclosing the dense basaltic core and attains an elevation of 6,823 feet. The basalt in the core is dark and lacks a well defined jointing pattern. Commonly the basalt weathers unevenly on its surface and gives an appearance of spalling in thin sheets, possibly indicative of an autobreccia. Large blocks of sandstone are enclosed in the breccia both in the central part of the peak and on the external faces. The sizes of these sandstone inclusions vary greatly. Some large blocks are nearly rectangular in shape and are up to 3 feet long and 2 feet wide. Other pieces are only a few millimeters in length and width. The sandstone xenoliths appear severely baked, often appearing cherty. The xenoliths are also bleached white or grayish-white. On the northeast

face of the peak the sediments are in horizontal contact with the vertically rising breccia shell and exhibit no signs of undulation or extensive heat metamorphism.

Extending southeast from the main peak is a high and rather narrow ridge cut by a succession of three dikes (striking S.85^{O}E. and vertical) perpendicular to the ridge crest (Pl. 22). The ridge is terminated by a sheer face of massive basalt. The dikes stand approximately 4 feet above the ground surface on the ridge crest and disappear under the sediments to the east and west, extending for a distance of 200 feet in each direction. The dikes are 50 to 100 feet apart and regularly spaced. Within the basalt forming these dikes are vitreous xenocrysts of augite and hypersthene. The augite contains exsolution lamellae of an orthopyroxene, probably hypersthene. These xenocrysts appear similar to those described by Brunton (1952) at Cerro de Guadalupe. The dikes exhibit an ill defined columnar jointing pattern that is perpendicular to the strike of the dikes. The more massive dike terminating the south end of the ridge has short columnar joints that have no well defined trend.

The breccia shell of the main peak is composed mostly of glass with grains of angular quartz. Also enclosed in the breccia glass are rock fragments, seemingly

Plate 21. Basaltic core of Seboyeta Peak with breccia shell (left).

Plate 22. South from Seboyeta Peak along ridge cut by dikes.

basaltic. The minerals of the included rock fragments are almost impossible to determine due to intense oxidation and the subsequent formation of hematite and limonite on the remaining grains. The quartz grains are commonly intensely fractured internally and possess highly angular boundaries. The quartz exhibits no evidence of resorption or assimilation. Probably present, though unidentifiable optically, is a clay mineral which is the matrix of the sandstone.

The basalt is trachytic to felty, intersertal, and microporphyritic. Olivine, present in significant amounts at other localities, is practically absent in the basalt at Seboyeta Peak. Only a small amount of olivine, occurring as microphenocrysts, is present in the southernmost dike. No olivine is present in any of the other dikes or within the basaltic core. The feldspar was found to be sodic labradorite. Other minerals present in the basalt are augite, hypersthene, and titanomagnetite.

The augite is generally euhedral, though some grains are irregularly shaped and fragmental. Cross sections of the augite do not possess good cleavage traces even though the grains are euhedral in outline. Hypersthene occurs only in xenocrysts. It is absent in the groundmass. As previously mentioned, the augite contains exsolution

lamellae of an orthopyroxene thought to be hypersthene. Augite constitutes 15 to 20 percent of the basalt and 60 percent of the xenocrysts. Plagioclase, forming 40 percent of the total basalt, often occurs as anhedral crystals and displays albitic zoning in most instances. The laths often surround glass and smaller grains of pyroxene and feldspar. Where they form a trachytic texture, the plagioclase laths are commonly better formed and display more distinct twinning than where the texture is felty or slightly trachytic.

Glass is present in most samples, constituting up to 15 percent of the groundmass. Generally, the glass is evenly distributed throughout the groundmass, though glass pockets are not uncommon. Titanomagnetite, constituting 10 percent or more of the basalt, occurs in small grains less than 0.1 mm in diameter and is evenly disseminated in the groundmass. Seldom are the opaque grains observed as inclusions within pyroxene grains. Magnetite is more abundant in the main basaltic mass (12 percent) and is less abundant in the dikes (8 to 10 percent). Also present in small amounts is chalcedony, forming veinlets and rimming cavities. Calcite, again closely associated with the xenocrysts and forming cavity fillings, is present in addition to natrolite, occurring as minute spherulites

filling cavities and often associated with the calcite. The greatest abundance of secondary minerals is observed in the southernmost dike, where the minerals constitute nearly 10 percent of the rock.

CHEMICAL COMPOSITION OF THE BASALTIC ROCK

The chemical composition and the norms (modified CIPW) of the basalt selected from some of the necks are tabulated (Tables 1 and 2). They are typical alkali basalts containing low silica (44-47%), high K_2O (0.90-1.74) and high total alkalies (>4%). Most of them show nepheline (up to 5.52%) in the norm; very little normative hypersthene is present and, of course, no normative quartz. Such compositions with high alkali and potash contents are characteristic of most upper Tertiary basaltic rocks from the Basin and Range and Southern Rocky Mountain Provinces (Moore, 1962), although the Puerco basalts are more undersaturated. A typical oceanic alkali basalt is included in Table 1 for comparison (Engel, et al., 1965, Table 5, sample PV 50). On alkali-silica and potash-silica diagrams these basalts plot well within the alkali basalt field.

No systematic variation is apparent from peak to peak throughout the whole field. However, the relative proportions of normative albite and anorthite are variable. In some samples the albite:anorthite ratio is about 2, whereas, in one sample the ratio is less than one. These variations have not been correlated with any significant feature in the mineralogy of the basalts.

Table 1. Analysis (by Dr. Ken-ichiro Aoki) of the basaltic host rock of the Rio Puerco necks.

	1	1a	2	3	4	5	6
SiO_2	46.63	45.41	44.95	47.03	45.65	44.05	45.33
TiO_2	2.13	2.06	3.33	2.18	2.88	3.47	3.53
Al_2O_5	13.78	13.55	15.25	14.33	14.00	13.71	15.50
Fe_2O_3	3.37	5.88	2.48	3.65	2.98	3.96	1.81
FeO	9.72	6.49	8.81	8.77	9.94	10.16	10.64
MnO	0.19	0.17	0.19	0.20	0.19	0.21	0.23
MgO	9.13	8.28	7.91	7.99	8.38	8.38	6.77
CaO	7.87	7.27	9.50	8.20	7.71	8.26	8.50
Na_2O	3.25	3.73	2.87	3.65	3.67	3.53	4.30
K_2O	1.30	0.91	1.33	1.36	1.74	0.90	2.36
H_2O^+	1.63	3.72	2.06	1.37	1.28	1.67	0.20
H_2O^-	0.48	1.79	0.70	0.32	0.74	0.57	0.01
P_2O_5	0.43	0.47	0.51	0.61	0.66	0.61	0.73
Total	99.91	99.72	99.89	99.66	99.82	99.56	99.91

1. Cabezon, 1a. Cabezon Peak, autobreccia (?), 2. Cerro Cochino, 3. Cerro de Guadalupe (weathered), 4. Cerro Vacio, S. Seboyeta Peak, 6. Analysis taken from Engel, et al., 1965 Table 5, sample PV 50.

Table 2. Modified CIPW norms. 1. Cabezon Peak, 1a. Cabezon Peak, autobreccia, 2. Cerro Cochino, 3. Cerro Vacio, 4. Seboyeta Peak.
Note: The sample from Cerro de Guadalupe was too severely weathered to produce meaningful norminative values. Symbols for the normative minerals are standard.

	1	1a	2	3	4
Or	7.90	5.70	8.10	10.50	5.50
Ab	29.45	35.55	23.00	24.50	27.15
An	19.72	18.62	25.70	17.00	19.62
Ne	0.33		2.19	5.52	3.42
Di	14.04	13.16	15.76	14.28	15.04
Hy		2.62			
Ol	21.03	13.74	16.68	19.55	18.67
Mt	3.61	6.53	2.67	3.18	4.29
Il	3.00	3.04	4.80	4.10	5.00
Ap	0.93	1.04	1.09	1.37	1.31
Total	100.01	100.00	99.99	100.00	100.00

In Hawaii, basaltic hosts containing abundant lherzolite inclusions are most commonly olivine nephelinite with normative nepheline in excess of 14% (White, 1966). The alkali basalts in Hawaii are completely lacking in lherzolite inclusions but more abundant in wehrlite, dunite, and gabbro inclusions. As will become evident in the following discussions, the alkali basalt of the Puerco Necks contain abundant lherzolite.

ULTRAMAFIC INCLUSIONS

The ultramafic inclusions in the area consist of two main types: lherzolite and websterite (for chemical compositions see Table 3). Lherzolite inclusions are as xenoliths in the basalt. Websterite's occurrence is more limited than that of the lherzolite. The websterite inclusions are generally rather small, such as those at Seboyeta Peak and Cerro de Jacabo. However, websterite xenoliths measuring up to 20 cm are present at Cerro de Guadalupe and Cerro Negro. Inclusions of intermediate composition such as harzburgite and wehrlite are not present. One sample of a plagioclase-rich gabbro was found at Cerro Negro (Table 4).

Petrology of the lherzolite inclusions

The greatest abundance of lherzolite inclusions occurs in the lower peak of Cerro Negro. The macroscopic associations of these inclusions with the basaltic host have been previously discussed. The inclusions are angular to subrounded at Cerro Negro and all other localities in the area. No evidence of glassy or chilled zones are present in hand specimen or thin section around these inclusions.

The lherzolite inclusions are generally composed of 80 to 90 percent olivine, 5 to 10 percent orthopyroxene,

Table 3. A comparison of the chemical analyses of ultramafic inclusions of the Rio Puerco necks with those encountered elsewhere in the world (weight percent).

	Lherzolite	Websterite	Upper Mantle (I.G. White, 1967)	Average Inclusion (Ross, Foster & Myers, 1954)
SiO_2	42.71	50.90	44.5	40.87
TiO_2	0.11	0.23	0.15	0.02
Al_2O_3	2.00	7.29	2.55	0.07
Fe_2O_3	2.17	2.30	1.5	0.00
FeO	5.99	3.72	7.3	8.72
MnO	0.13	0.15	0.14	0.15
MgO	41.93	20.96	41.7	49.78
CaO	2.75	12.43	2.25	0.07
Na_2O	0.15	0.74	.25	0.01
K_2O	0.05	0.05	.015	0.00
Cr_2O_3	.32	---	---	0.02
Total	100.42	99.73	100.36	99.71

and 5 to 10 percent clinopyroxene. Opaque grains are not present in the lherzolite. Spinel (variety picotite) is present only rarely in the lherzolite inclusions.

The texture of the lherzolite is xenomorphic-granular in all observed xenoliths. Only rarely is an euhedral grain present, and it is usually olivine. Grains of clinopyroxene often have fine exsolution lamellae of orthopyroxene. Exsolution lamellae of clinopyroxene in the orthopyroxene are rare and generally poorly developed. Orthopyroxene (particularly hypersthene) also occurs poikilitically in the clinopyroxene where it usually possesses strong pleochroism. Where poikilitic orthopyroxene occurs, exsolution lamellae in the clinopyroxene are absent. Olivine does not occur as poikocrysts in any instance.

The clinopyroxene present in the lherzolite generally occurs as elongate crystals lacking preferred orientation. For analysis see Table 4. Distinguishing diopside from augite is difficult optically. Diopside is present in hand specimen and easily identifiable by its emerald green color. It does not constitute more than 5 percent of the lherzolite in hand specimen. Twinning in the clinopyroxene is absent. Grains of clinopyroxene commonly are present in direct contact with one another. Extinction

Table 4. Individual analyses of the olivine, clinopyroxene, and orthopyroxene in the Lherzolite inclusions. Also included is the gabbroic inclusion from Cerro Negro.

	Olivine	Clinopyroxene	Orthopyroxene	Gabbro
SiO_2	40.47	53.08	55.60	53.79
TiO_2	0.00	0.09	0.07	0.23
Al_2O_3	0.28	3.60	2.75	20.70
Fe_2O_3	0.67	1.17	0.68	2.58
Cr_2O_3	---	0.80	0.47	---
FeO	8.47	2.06	5.41	3.21
MnO	0.14	0.07	0.10	.11
MgO	49.20	17.19	33.10	5.50
CaO	0.05	20.31	1.20	7.06
Na_2O	0.00	0.86	0.10	3.79
K_2O	0.00	0.03	0.02	1.05
H_2O	0.50	0.43	0.33	1.58
P_2O_5	---	---	---	.02
Total	99.78	99.69	99.83	99.62

is sharp and no zoning is present.

The orthopyroxene in the lherzolite generally occurs as anhedral crystals lacking preferred orientation. Enstatite is rare compared to hypersthene. Often enstatite is absent from the lherzolite, particularly from the smaller inclusions. Twinning, as well as exsolution lamellae, are absent in the orthopyroxene. Schiller structure is also absent. Enstatite is present only in the larger inclusions such as those at Cerro Negro as dark brown interstitial grains and is nearly opaque in thin section. X-ray analysis indicated that the mineral is an orthopyroxene, and it was further defined as enstatite on the basis of the optical characteristics of fragments. Hypersthene lacks pleochroism and parallel extinction in many instances but is identified by its optic sign.

Olivine displays severe fracturing in nearly every sample and does not indicate any evidence of alteration to pyroxene in the lherzolite. Commonly the olivine is twinned in broad, uneven lamellae. The grains are generally anhedral and equidimensional. However, rare elongate grains are present.

In the basalt adjacent to the lherzolite inclusions laths of plagioclase are parallel to the inclusion's outlines.

The parallelism is generally dominant on only one side of the inclusion. Also, reaction rims consisting of mottled and cloudy edges on the lherzolite material are often present. However, inclusions commonly display no signs of reaction with the surrounding basalt. Fragmental grains of lherzolite minerals, probably from the inclusion, unevenly dispersed in close proximity to the inclusion invariably have reaction rims, particularly olivine, which is rimmed with clinopyroxene and magnetite. Calcite is often associated with the larger inclusions and generally occurs in vesicles on the margins of the inclusion. Calcite is considered deuteric, for if it were primary, it would have acted as a flux and would have facilitated reaction between the lherzolite and the basalt.

Petrology of the Websterite Inclusions

Inclusions of websterite are uncommon in the basalt forming the peaks. Only at the peaks of Cerro de Guadalupe, Cerro Negro, and Cerro de Santa Rosa is websterite present. Augite and hypersthene are the chief minerals of the websterite, although spinel is present rarely. At Cerro Negro the websterite inclusions are only 4 cm in their longest dimension and are dark green in color. Good cleavage planes are also present on the mineral surfaces.

At the other localities the websterite minerals lack cleavage and are dark brown. The websterite at Cerro Negro is intensely weathered and is ovoid shaped. The websterite at Cerro de Santa Rosa is surrounded by a glassy rim of basalt in hand specimen. In thin section this rim is composed of a very fine grained mosaic of pyroxene grains that invade the peripheral inclusion grains. The inclusions are generally subrounded to rounded in outline. In one example at Cerro Negro a xenolith consisting of both lherzolite and websterite is present. These two assemblages are in direct contact with one another (Pl. 9). Opaque mineral grains are generally absent from the inclusions, although the websterite inclusion discovered at Cerro de Santa Rosa contains nearly 5 percent of pyrrhotite, chalcopyrite, ilmenite and chromite.

Texturally, the websterite is xenomorphic-granular. The grains are usually interlocking without preferred orientation. Poikilitic structures are absent with the exception of Cerro de Guadalupe where hypersthene is enclosed in clinopyroxene.

A distinction was not made between augite and diopside. In thin section the clinopyroxenes are colorless with ill-defined cleavage traces. Discontinuous exsolution

lamellae of orthopyroxene are ubiquitous. Generally these lamellae are thicker than those present in the lherzolite but do not always extend the total length of the crystal grains. Fine, almost invisible, and discontinuous lamellae are also present. Zoning is rarely present. The clinopyroxene composes 60 percent of the websterite.

Enstatite is present in minor amounts as interstitial and poikilitic grains in the hypersthene. It is very dark brown and nearly opaque in thin section. Hypersthene displays pleochroism from light reddish-brown to clear to dark reddish-brown. The hypersthene commonly has a dingy brown color in thin section. Exsolution lamellae of clinopyroxene are present in nearly every hypersthene grain as continuous, thin lamellae. Cleavage is generally well defined and no zoning is present in the orthopyroxene. The orthopyroxene constitutes 40 percent of the rock.

Discussion of Ultramafic Inclusion

A great deal of previous work has been conducted on ultramafic inclusions found in basaltic and ultramafic rocks. Chemical analyses of inclusions from occurrences all over the world indicate that the mineralogy and chemistry of the inclusions are remarkably similar. The inclusions in this area fall well within the boundary compositions of the

other inclusions analyzed (Ross, Foster, and Myers, 1954). Extensive work on the websterite inclusions and their chemistry have not been conducted, though in the available information, the chemistry of these inclusions is similar to that of pyroxenes found in gabbroic and ultramafic rocks (Aoki, 1967; R. White, 1967). One feature concerning the chemistry of the websterite is of particular importance. The Al_2O_3 content of the websterite is significantly higher than that found normally in terrestrial samples of ortho- and clinopyroxenes. Also, the TiO_2 content is significantly lower (Deer, Howie, and Zussman, 1963). Aoki (1967) explained these differences by pressures of formation, a higher pressure (11 kb) markedly decreasing the solution of titanium and increasing that of aluminum in the pyroxene lattice. The lherzolite composition falls within the compositional range of peridotites (I. G. White, 1967).

Volumes of material have been published concerning the earth's inner composition and phase relationships, particularly in the mantle region. Numerous models have been advanced and the one generally accepted consists of an upper mantle of dunite-peridotite and lower zones caused by mineralogic variations (Ringwood, 1962; Green and Ringwood, 1963; I. G. White, 1967). Basalts are thought to be derived

from the ultramafic mantle by a partial fusion process.

The hypotheses concerning the origin of the ultramafic inclusions observed in other localities around the world are numerous. A listing of these hypotheses is presented below (after White, 1966).

1. Inclusions are products of the enclosing basaltic rock and are clusters of phenocrysts which formed within host magma.
2. Inclusions are fragments of primary mantle material, and are the same as the material from which the enclosing basaltic material was produced.
3. The basaltic magma was produced by partial or total fusion of fusible portions of heterogeneous primary mantle. Inclusions are fragments of infusible portions of the mantle; they are not residual from the fusible portion, nor are they the same as the original material from which the basaltic magma was produced.
4. Inclusions are exotic fragments of mantle material, and are unrelated to production of the enclosing basaltic magma or to its differentiation.

This listing is not complete but expresses the general views held by most geologists concerning the nature of ultramafic inclusions.

The proposed origin of the inclusions in the area consists of a combination of some of the ideas presented above. The inclusions are not accumulations that crystallized from the enclosing basaltic magma. The inclusions also do not contain any basaltic minerals such as plagioclase or opaques interstitially as would be expected if the inclusions were accumulations. Further, the evidences of reaction between the basalt and the inclusions suggests inequilibrium between the inclusions and the basalt. The reaction is most evident where fragments of olivine are present in an area adjacent to a larger inclusion. Also, some boundaries of inclusions indicate reaction. If the inclusions were aggregates, a more euhedral grain shape would be expected rather than the xenomorphic-granular texture present in these inclusions.

For the reasons cited above it is proposed that the inclusions and the basalt are not coexisting phases. It is suggested that the basalt and the inclusions were both generated from a depth between 35 and 40 km beneath the earth's surface (Al_2O_3 solubility, Wilshire and Binns, 1961).

The inclusions represent the residue of partial fusion of mantle material (dunite-peridotite) and the basalt is the liquid resulting from this partial fusion of mantle material. This is not to say that the inclusions are pieces of the mantle any more than the basalt is a piece of the mantle, but rather that these two rocks together represent the mantle composition from which they were derived (Table 5). Combination of the chemistry of the alkali basalts and the inclusions has a composition roughly comparable to the proposed composition of the upper mantle (Ringwood and Green, 1963). These inclusions were enclosed in the basaltic melt and brought to their present position on the earth's surface.

The textural evidence indicates that extensive reaction between the ultramafic inclusion and the enclosing alkali basalt was limited. It may be interpreted from this that the inclusions were brought up quickly and that what heat was available for reaction was dissipated during the intrusive process, leaving little for assimilation. Besides, assimilation would not be significant nor noticeable, since the basalt was crystallizing the very source minerals, except for the hypersthene, that are contained in the inclusions.

Table 5. Comparison of proposed upper mantle composition proposed by Ringwood and Green (1963) with mixtures of the average Puerco alkali-basalt, lherzolite, and websterite in ratios indicated. (The ratios are alkali basalt: lherzolite: websterite).

	Upper Mantle (Ringwood and Green, 1965)	1:1:1	1:3:1	1:4:1
SiO_2	44.69	46.41	45.13	43.22
TiO_2	---	1.00	.65	.13
Al_2O_3	4.09	7.80	5.48	1.25
Fe_2O_3	---	2.73	2.51	.78
FeO	7.81	6.23	6.13	5.61
MnO	---	.16	.17	.16
CaO	3.19	7.77	5.76	5.26
MgO	39.08	23.91	31.12	32.92
Na_2O	1.14	1.44	.93	.80
K_2O	---	1.36	.29	.25

MODE OF INTRUSION

In considering the modes of intrusion of the basaltic masses, several factors must be taken into account. The surrounding Cretaceous sediments are not deformed by the intrusion of the rocks although they have been "stoped" as inclusions by the basaltic magma. In numerous places large pieces of the country rock are enclosed in a type of scoriaceous basalt which is present at nearly every locality and which commonly forms a cap. In certain instances, for example Seboyeta Peak, the scoriaceous material with the included sediment fragments forms an envelope around the massive basaltic core. In numerous other examples breccia and scoriaceous matter form a significant amount of the peak such as is present at Cerro de Guadalupe and Cerro Negro. Regular and relatively undisturbed columnar jointing patterns are not a predominant feature in the peaks. The larger peaks of Cabezon and Great Neck Peak (Cerro de Nuestra Senora)possess relatively undisturbed jointing patterns that flare regularly at the base, but smaller peaks such as Cerro Vacio and Cerro Negro display a great deal of complexity in the attitudes of their jointing. It is unlikely that extensive lava extrusion in the immediate vicinity of each peak ever took place. The large mesas

present on either side of the area and the geomorphic features within the area such as small sandstone-capped mesas would suggest that much more resistive caps of igneous rocks surrounding a basaltic core would also be preserved and be present at least as vestiges.

The emplacement of the basaltic cores, production of the scoriaceous and breccia material, and formation of the erratic jointing patterns can be explained in three main intrusive stages. The intrusive stages are the following: 1) primary injection of the basaltic mass and accompanying formation of scoriaceous and brecciated material; 2) partial cooling of the injected mass and formation of primary columnar jointing patterns; 3) reinjection of magma into contraction cracks and fissures resulting from the cooling of the emplaced magma. The hypotheses presented for the intrusion are relevant only to the processes occurring at relatively shallow depths within the crust. They are similar to those proposed by McBirney (1959). At depths greater than 2 to 4 km the intrusive mechanisms remain unresolved.

The initial stage consisted of expelling gases and water vapor from the magma as well as subsequent formation of a basaltic froth. Accompanying the volatile expulsion from the magma would be the release of large quantities of

heat into the overlying and colder sediments. The heat and gas would diffuse into the sediments causing an increase in the pore pressure of the rock. The effects of volatile invasion would be much less than the thermal effects. The heat would cause expansion and vaporization of the interstitial water in the sediments and, combined with the induced volatiles, would greatly increase the rock's pore pressure. If enough heat were available, an inversion of α-quartz (density = 2.65) to tridymite (density = 2.30) could take place, increasing the pore pressures and making the rock become brittle and susceptible to fracture (McBirney, 1959). The fractures could then be easily invaded by the magma which would closely follow. Additional heating of the country rock would result and the fractured and broken pieces would soon become dislodged from the channel walls and roof and easily incorporated into the magma as brecciated inclusions.

A convection cell in the rising magma column would be present that would transport the fragmented country rock down the sides of the channel where the material could be "stoped" or removed from the path of the rising magma (Fig. 4). The convection cell would be accentuated due to the heat loss resulting from the rock fracturing and

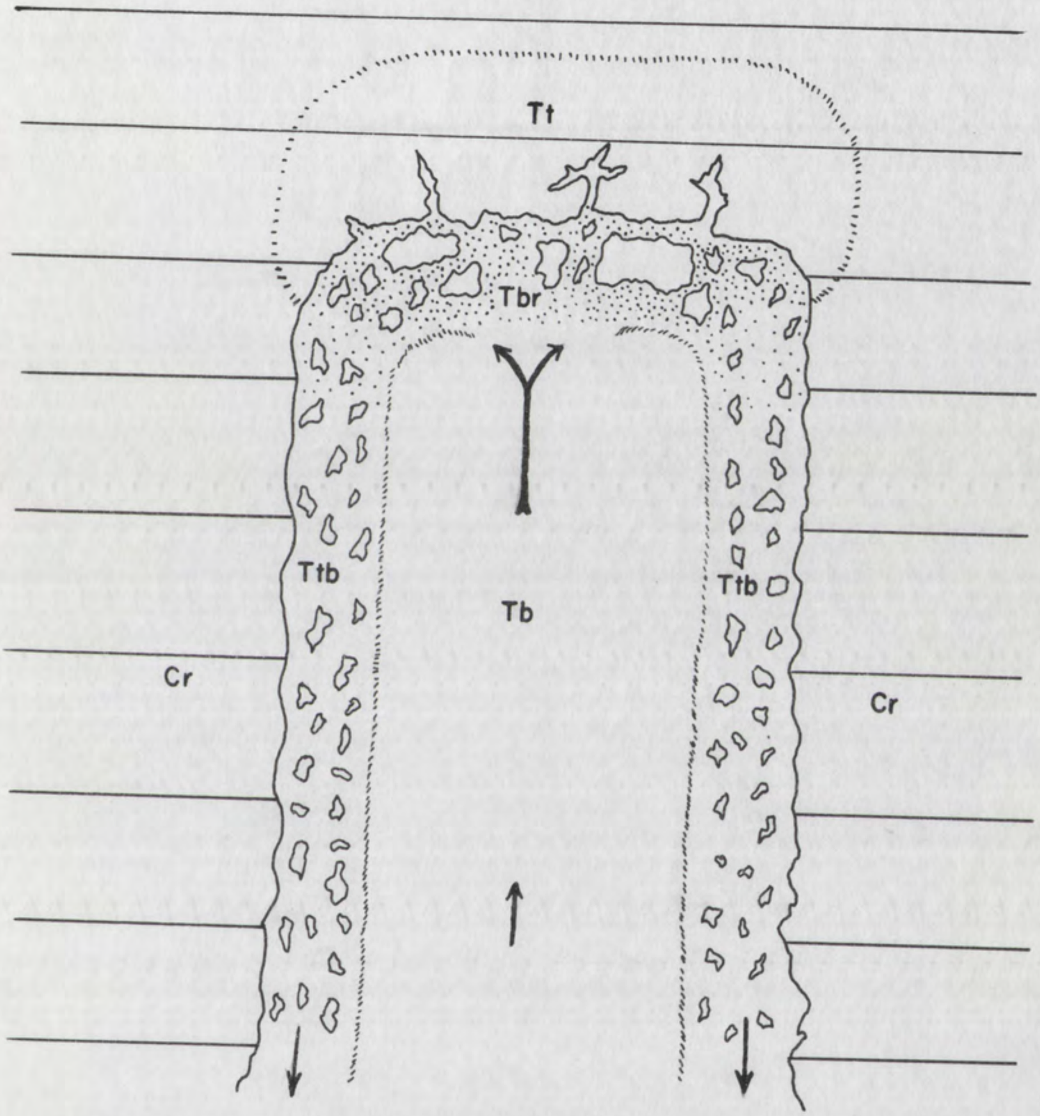


Figure 4. Hypothetical convection cell for the intrusion of the Rio Puerco bodies. (Cr-country rock, Tt-zone of maximum heat effects, Ttb-zone of down flowing magma and transportation of broken country rock, Tb-zone of the upwelling new magma and accompanying heat influx, Tbr-zone of breccia formation)

dissipation into the sediments. New material would be continually rising in the center of the channel, and the cooler brecciated material would move down along the channel walls in an attempt to establish thermal equilibrium in the system. The smaller density of the country rock compared to the magma density presents the problem of rapid transportation. An effective velocity would necessarily depend on the particle size, the larger fragments being more likely to "float" than smaller fragments at any given convection velocity. Abrasion of the larger fragments would decrease their size and facilitate their removal from the rising magma's path. This process would necessarily be rapid, due to the large amount of heat consumed in this process and the required heat transfer to maintain thermal stability within the system. This intrusive process would continue as long as heat was available from the rising magma column in a quantity large enough to overcome dissipation into the country rock. A more detailed discussion of this proposed phenomena is presented by McBirney (1959). This process would not deform the country rock during intrusion.

The second stage would be one of quiescence and cooling of the magma. Cooling would result in formation of

regular columnar jointing patterns and creation of cooling cracks or fissures within the interior of the body. The interior regions would cool more slowly than the periphery though regular jointing patterns of a coarser nature would develop. This stage of cooling would be an important factor governing the third stage of intrusion.

In the regions below the cooling portion of the magma convection currents would still be active. The magma would persist in attempting to maintain thermal equilibrium between the solidifying magma and the underlying still molten magma. When cooling and contraction cracks formed in the upper masses, the underlying molten magma would fill these areas due to pressure decreases in the overlying masses. This secondary injection could create movements in the overlying solidified or partially solidified mass and result in the distortion of the already formed jointing systems. This distortion would be more evident in the smaller bodies due to their more rapid cooling rates and smaller masses. The larger bodies would be less susceptible to this phenomena due to their retarded cooling rates and the subsequent contemporaneous cooling of the underlying magmas. The larger bodies would tend to cool evenly at depth due to the longer periods of time required for their cores to cool. The

extended times involved in this instance would lessen the possibility of the third stage injections and result in the development of more regular jointing systems such as that of Cabezon Peak.

Judging from the restricted reaction between the olivine and pyroxene xenocrysts with the magma, it appears likely that a great deal of the inherent heat and the heat of crystallization was consumed during the intrusive process rather than in assimilation. Heat normally consumed by assimilation would not have been needed since assimilation probably did not take place. The basaltic magma was crystallizing olivine and augite which occur as micro-phenocrysts. These minerals are identical to those contained in the ultramafic inclusions; consequently, assimilation need not occur (Bowen, 1928). The heat unused for assimilation would definitely aid the intrusive process.

The preceeding discussion is primarily concerned with an intrusive mechanism relevant only at shallow depths. The mode of intrusion up to this shallow depth was no doubt more forceful. Alignment of certain of the bodies such as the two peaks of Cerro Negro with Seboyeta Peak, as well as the general trend of the entire area suggests a deep seated dike-like feeder to the peaks. Elongation of some of the

bodies, such as Cerro Cochino and Cerro Vacio, indicates that a forceful mechanism was present at shallow depths within the field. The convection mechanism discussed previously lends itself to formation of a cylindrical body rather than an elongated one. Also, the two peaks of Cerro Cochino and Cerro Vacio have only minor amounts of associated scoriaceous material and no country rock breccia is present at either locality.

Hunt (1937) proposed that an extensive lava cap covered the entire area and has since been eroded away. He also proposed that Mesa Prieta is presently capped by a remnant of that sheet. The presence of scoriaceous material capping most of the peaks and the fact that extension of the base levels of the flows on the east and the west is above the level of many of the peaks' present elevations sheds a dubious light on the proposal that each of the bodies was a feeder vent to such a flow. Mesa Prieta has several small domal features within its lava cap that are more likely sources of the lava. The above evidence does not preclude the fact that a lava cap covered the present Rio Puerco valley. The evidence suggests that contributions to such an extensive flow from the peaks in the valley was unlikely.

The evidence does not suggest close association of

these bodies to the Mount Taylor eruptions with the possible exceptions of Seboyeta Peak and Cerro Negro. The chemical compositions of the basaltic peaks are not similar to the one basaltic sample from Mesa Chivato. Moreover, mineralogical differences are also present. In addition Mesa Chivato lavas are porphyritic (Dr. Ian Baker, personal communication, 1968). Therefore, it is difficult to correlate the lavas on Mesa Chivato with the Puerco rocks.

CONCLUSIONS

The peaks in the Rio Puerco valley are composed of alkali basalt consisting of augite, olivine, plagioclase (labradorite) and an opaque mineral (titanomagnetite). No systematic trends in mineralogy or chemistry are evident in the peaks suggesting that their primary origin was similar. The basalt was intruded rapidly with a large amount of heat dissipation into the country rock through the utilization of a convection cell that transported material out of the path of the rising magma. Assimilation of the country rocks was minor. It is unlikely that any of the intrusions reached the surface and contributed lava to form an extensive lava cap across the region presently occupied by the Rio Puerco.

Ultramafic inclusions of lherzolite and websterite in the basalts are probably mantle derived. They represent residual mantle material left during partial melting of the mantle which produced the alkali basalt. The inclusions were stable assemblages at the depths and temperatures of their formation and are not in equilibrium with the enclosing basalt. Furthermore, the inclusions were incorporated in the basalt as it moved upward from its region of origin. They are not crystal accumulations from the basalt.

APPENDIX

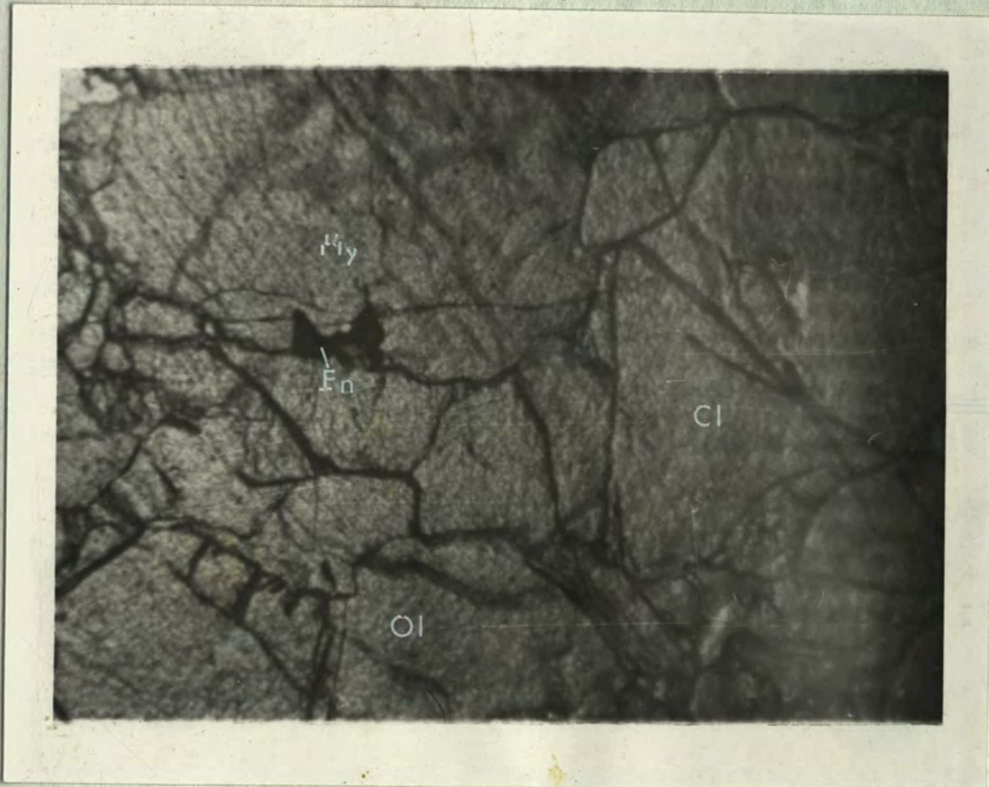
Sample Number	Location
Cabezon	
S-1	NW face
S-2C	NW face
S-3D	W face - autobreccia
CL-D1	W face - below autobreccia
2SS-1	S face
2SS-2	S face
2SS-3	SE face
2SS-4	SE face
2SS-5	SW face
2SS-6	WSW face
2SW-1	Xenolith, W face
2 SW-2	W face, around xenolith
Cerro Cochino	
CC-1	NE, jointed
CC-2	Corcarea, vesicular
CC-3	Core area, coarse
CC-4	WSW, crest
CC-5	Core
CC-6	E side, crest
CC-8	NW jointed
Cerro de Guadalupe	
NS-1	N face
NS-2	NE face
NS-30	"dike", N face
NS-4	NE face, "dike"
NS-5	NE face
NS-6	NW face
NS-7	NW face
NS-8	W face
NS-9	W face
G	Vesicular basalt, crest (?)
G-0	E face
G-1	NE face
G-2	E face, breccia
G-3	E face
G-4	SE, dike
G-5	S face
E-1	Sandstone xenolith
Great Neck Peak	
GN-1	NW face
GN-2	E face
GN-3	NE face
GN-4	W face
Cerro de Jacabo	
J-6	S talus

J-7		S, breccia
J-8		SE face
J-9		W face
J-10		NW face
J-11		NE face
J-12		NNE face
	Cerro de Santa Rosa	
J-1		SE-NE face, breccia
J-2		NE face, inclusion
J-3		NW face, inclusion
J-4		W face
J-5		W face
JM-1		NW face, inclusions
JM-2		N face, inclusion
	Cerro Chato	
CH-1		S face
CH-2		SW face
CH-3		WSW face
CH-4		NW face
	Cerro Vacio	
V-1		E face, coarsely jointed
V-2		E face, fine jointing
V-3		SW face
V-4		SW face, around sandstone inclusion
V-5		Sandstone inclusion, SW face
V-5A		W face
V-6		NE face
	Cerro Negro	
AS-1		S face
AS-2		SE face, "dike"
AS-3		E face
AS-4		N face
S-2-Z		SE face, sandstone xenolith, lower peak
N-dike		S face, lower peak
NLP-1		SW face, lower peak
DS-10		E face, lower peak
NW-1		Websterite, S face, lower peak
NV-1		Sandstone xenolith
NV-2		Sandstone xenolith
	Seboyeta Peak	
S-10		Core, main peak
DS-10		Dike in SW breccia
SM-10D		Ridge dike, second from peak
SM-11D		Ridge dike, second from peak

S-12	SW face, breccia
SS-10	Ridge dike, fartherst south from main peak
SS-11	S face, terminating dike
SS-12	S face, terminating dike
SS-14	SW face, terminating dike
SS-15	SE face, terminating dike

Plate 23. Xenomorphic granular texture of lherzolite inclusion from Cerro Negro (Ol-olivine, En-enstatite, Hy-hypersthene, Cl-clino-pyroxene. x35).

Plate 24. Xenomorphic granular texture of websterite inclusion from Cerro de Guadalupe (En-enstatite, Hy-hypersthene, Cl-clino-pyroxene. x35).


Hy
En
Cl
Ol

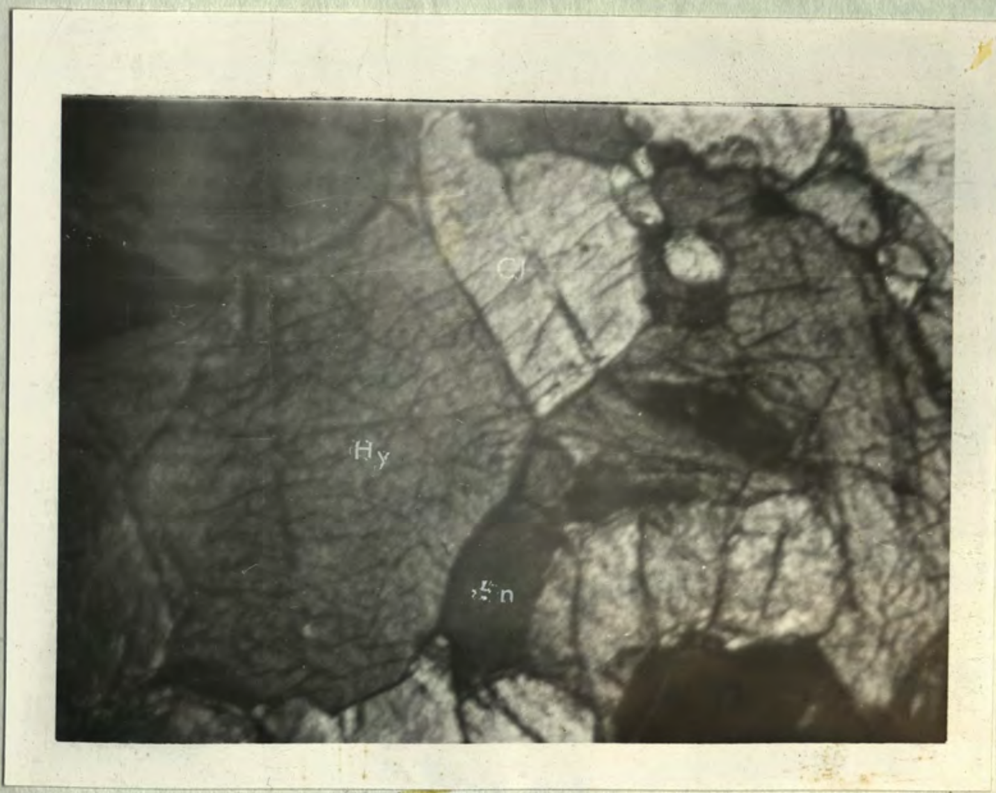
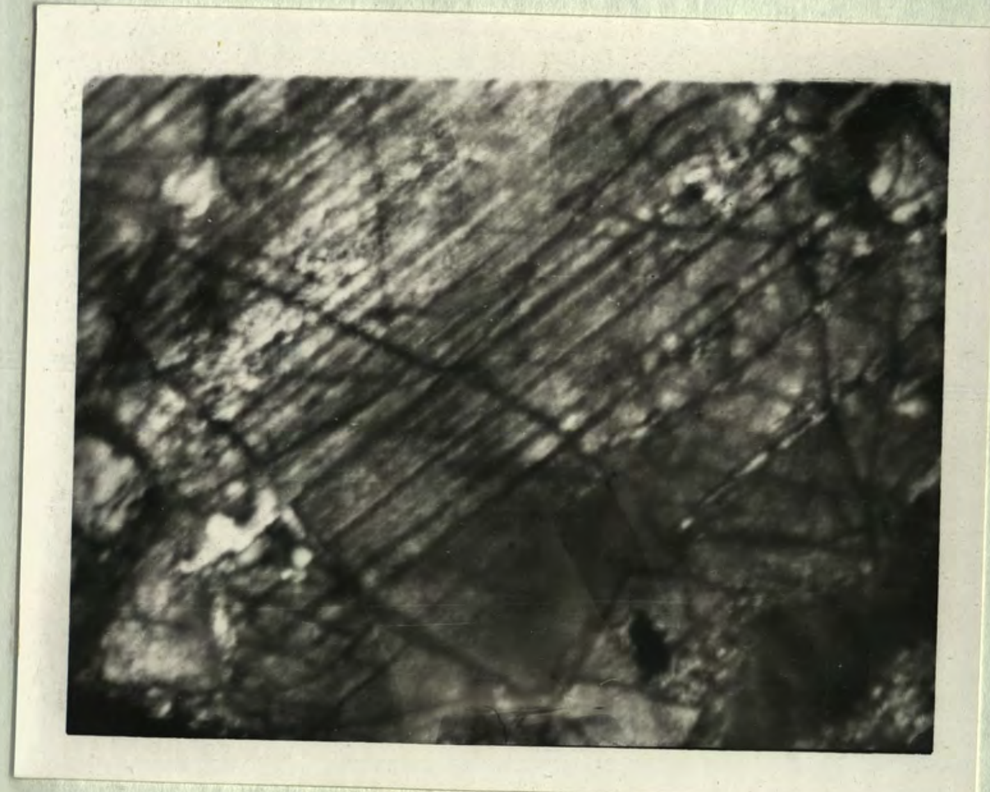

Cl
Hy
En

Plate 25. Exsolution lamellae of orthopyroxene in clinopyroxene (x35, crossed Nicols).

Plate 26. Clinopyroxene (Cl) and orthopyroxene (Ortho) in websterite inclusion, Cerro de Guadalupe (x35, crossed Nicols).




Ortho

Plate 27. Twin lamellae in olivine grain (x100, crossed Nicols).

Plate 28. Lherzolite (Ol-olivine, Hy-hypersthene, En-enstatite, Cl-clinopyroxene, x35, crossed Nicols).

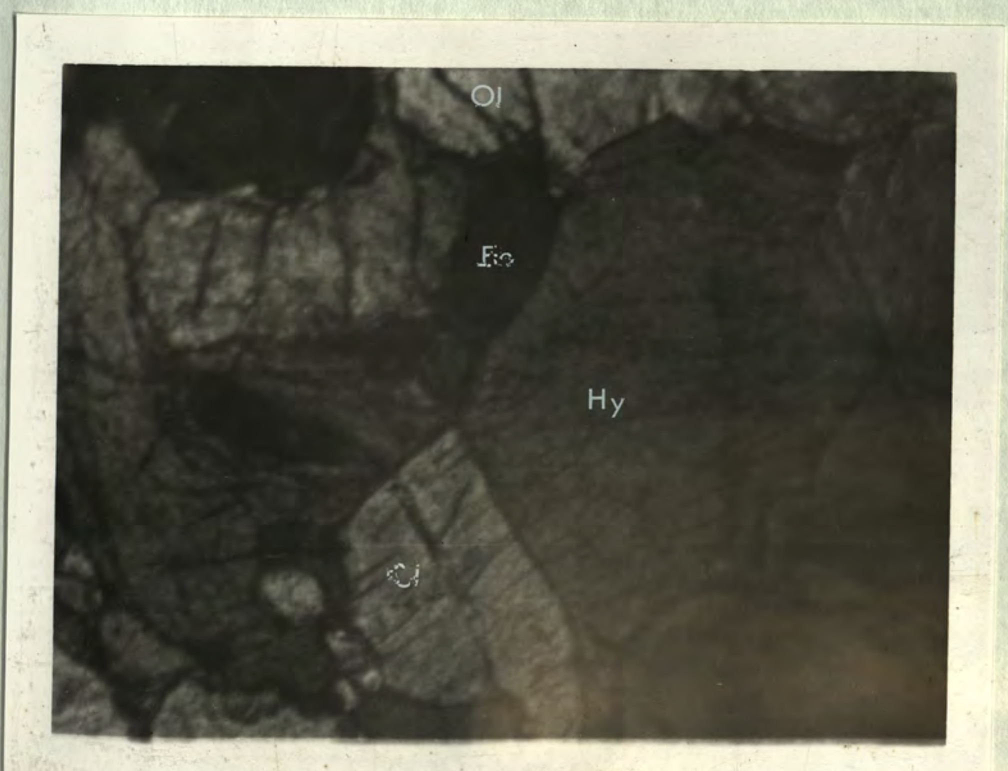
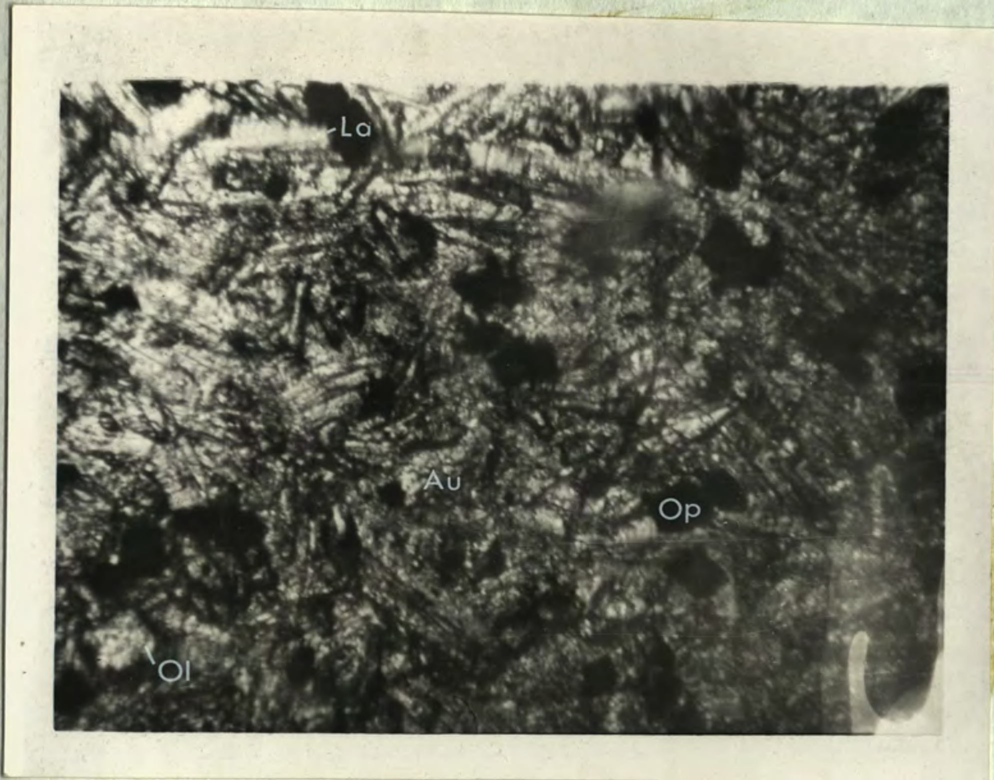
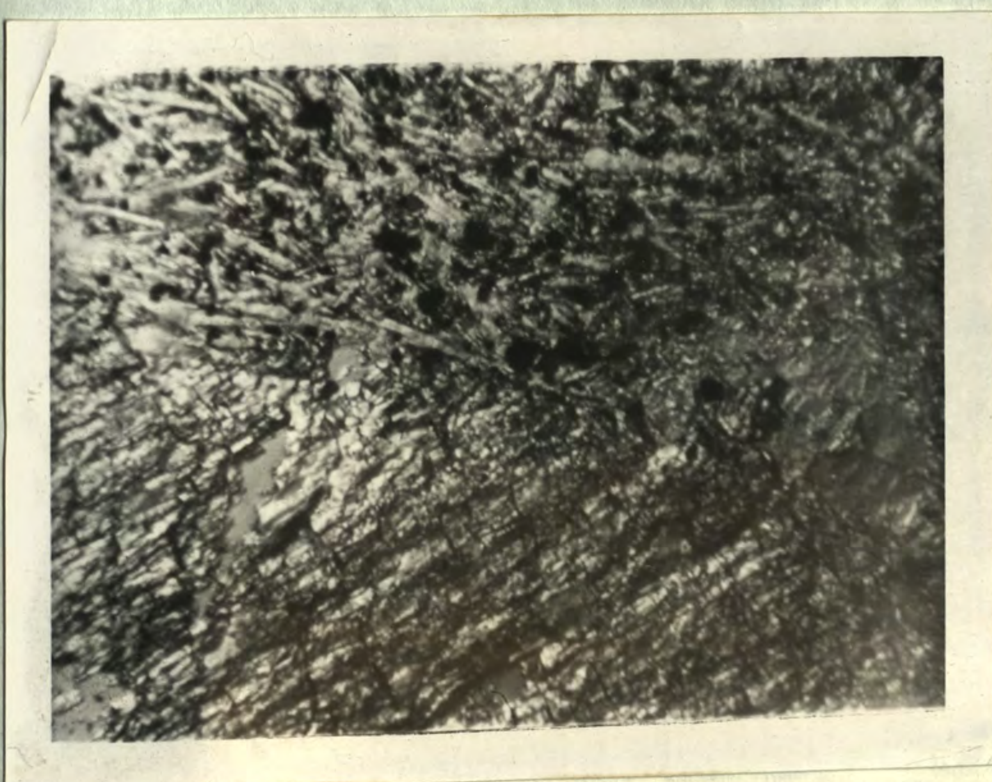

Ol
Fe
Hy

Plate 29. Slightly trachytic structure (Au-augite, La-labradorite, Op-opaques, Ol-olivine. x100).

Plate 30. Inclusion lacking reaction rim. (x100).


La
Au
Op
Ol



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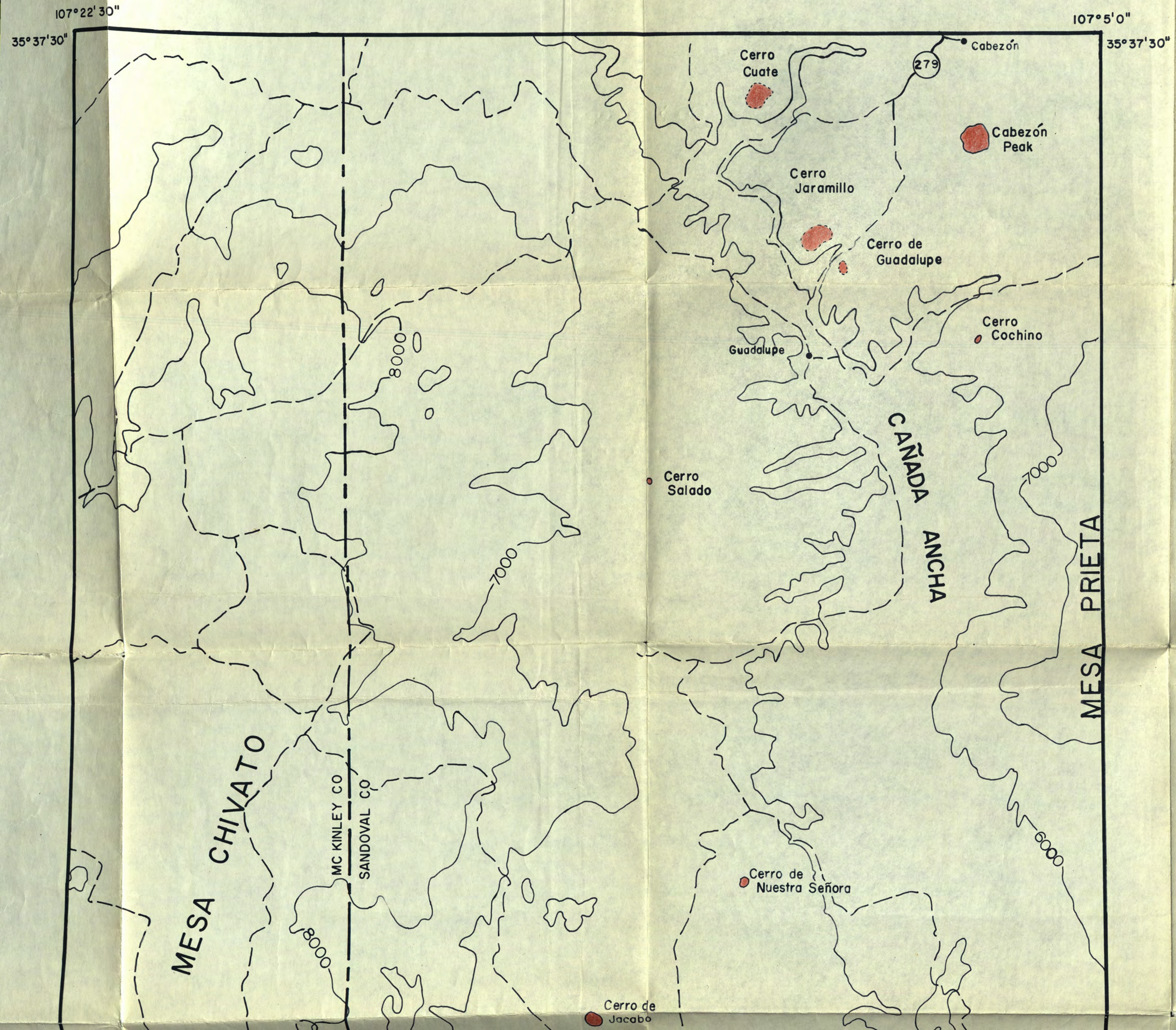
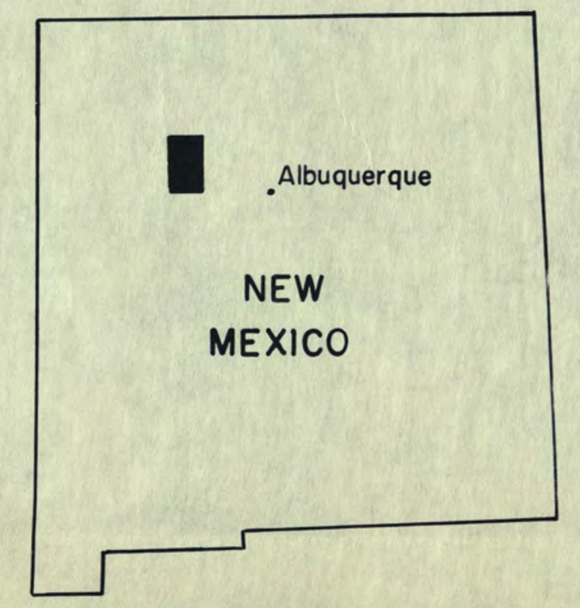
2 Figures (Figure 1 and Figure 3)

Figure I

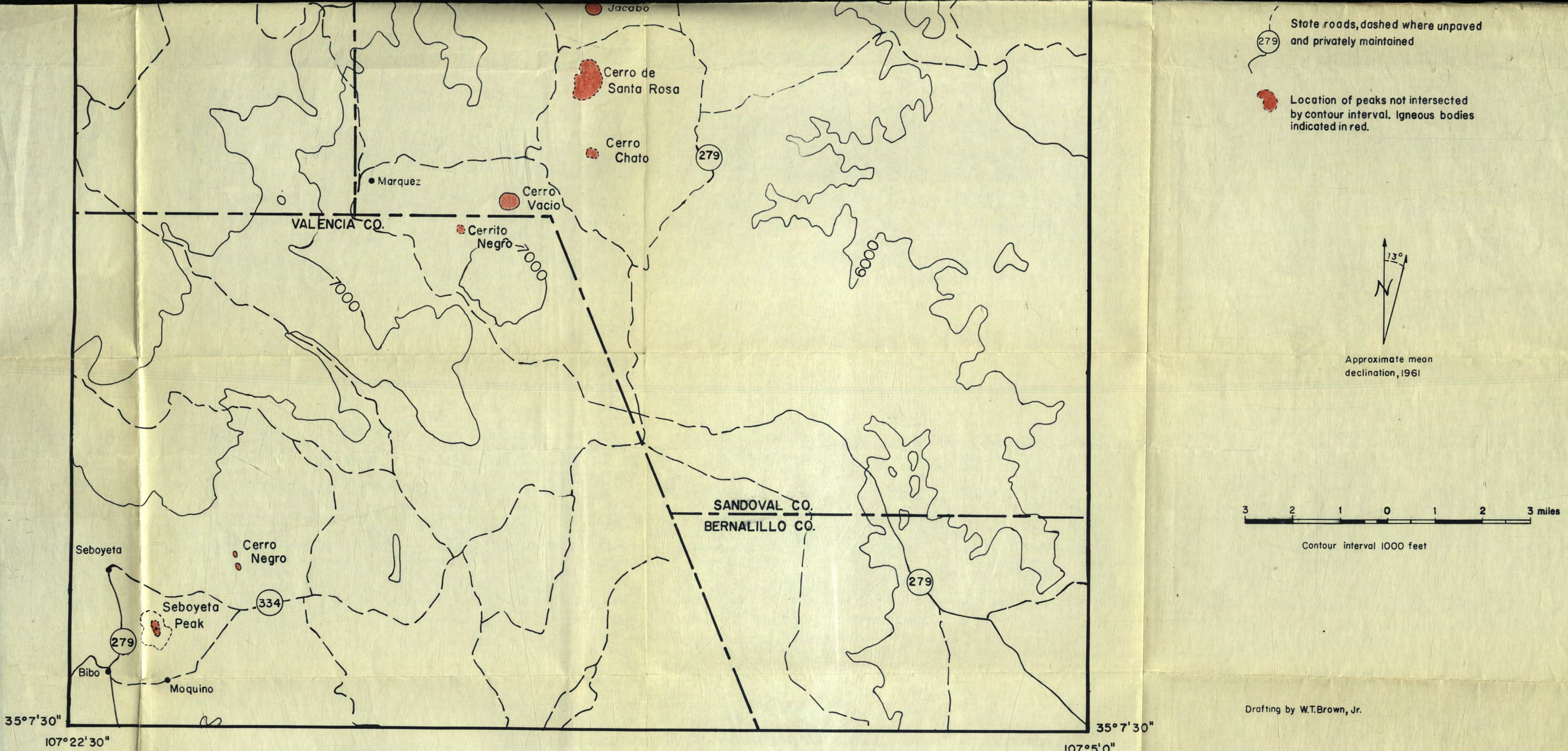
Location Map of the Igneous Bodies in the Rio Puerco Valley, New Mexico





Area Location

• Pueblos


Jacabo
Cerro de Santa Rosa
Cerro Chato
279
Marquez
Cerro Vacio
VALENCIA CO.
Cerrito Negro
7000
7000
6000
7000
SANDOVAL CO.
BERNALILLO CO.
279
Cerro Negro
Seboyeta
Seboyeta Peak
334
279
Bibo
Moquino
35°7'30"
107°22'30"
35°7'30"
107°5'0"
State roads, dashed where unpaved and privately maintained
279
Location of peaks not intersected by contour interval. Igneous bodies indicated in red.
13°
N
Approximate mean declination, 1961
3 2 1 0 1 2 3 miles
Contour interval 1000 feet
Drafting by W.T. Brown, Jr.

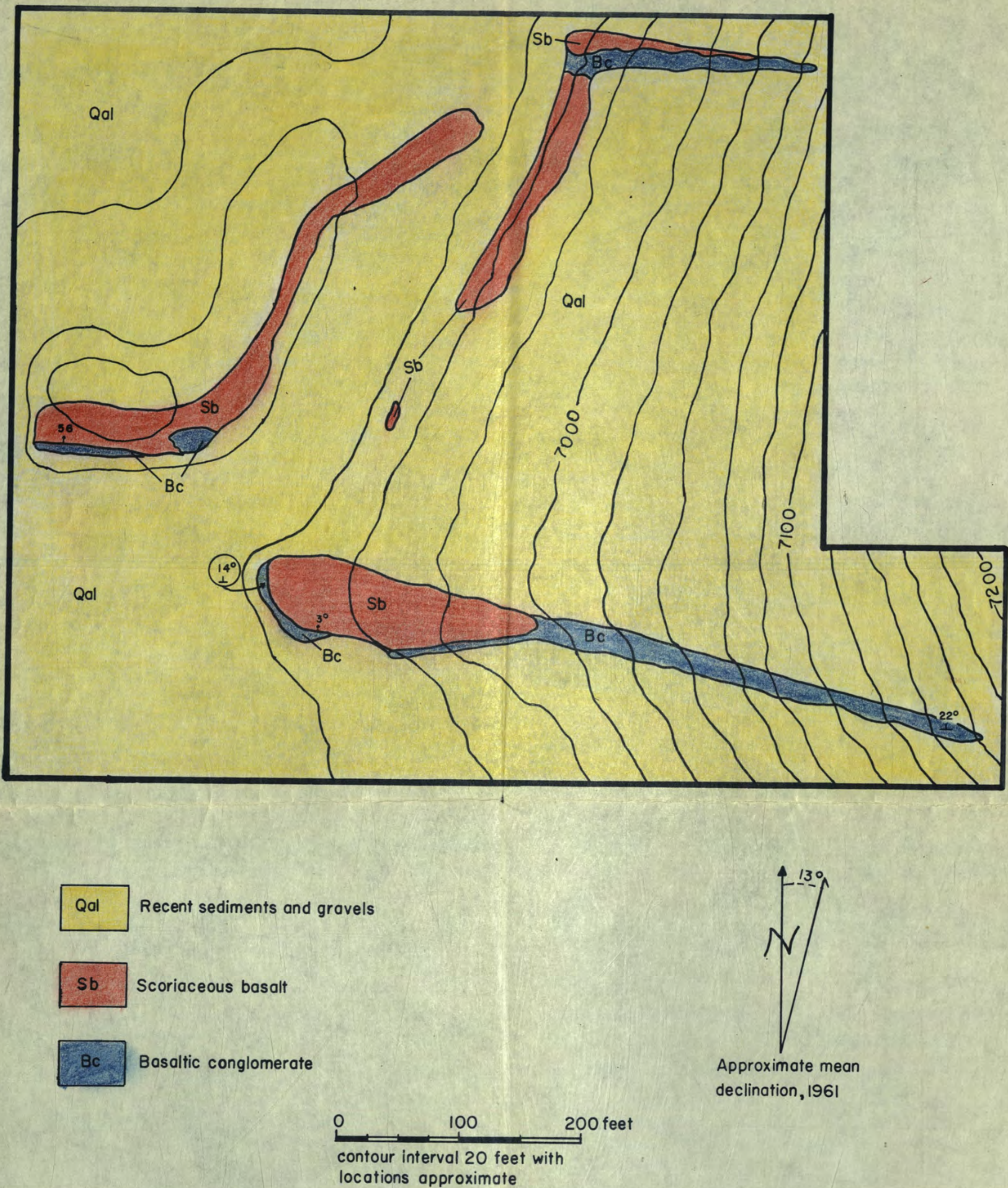


Figure 3: Outcrop map of formations 3/4 miles due west of Great Neck Peak