Geology of the Cerrillos Area, Santa Fe County, New Mexico

by ALAN E. DISBROW and WALTER C. STOLL

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Abstract

The center of the Cerrillos area lies 15 miles southwest of the city of Santa Fe in north-central New Mexico.

Strata ranging in age from the Upper Triassic Chinle formation to Recent alluvium are exposed in the area. Marine and continental sediments, chiefly sand and clay, were deposited during repeated advances and withdrawals of the Mesozoic sea. Throughout the Cenozoic era the Cerrillos area has been above sea level and subjected to erosion and the deposition of continental material.

Laramide uplift of the Sangre de Cristo Range resulted in a thinning by erosion of Upper Cretaceous strata at a rate of 130 feet per mile in a northeasterly direction. Subsequent deposition of sand, clay, and gravel of the Galisteo formation overlapped this surface toward the Sangre de Cristo Range.

In Oligocene(?) time uplift and complex folding and faulting occurred during the emplacement of a series of monzonitic stocks, plugs, laccoliths, sills, and dikes. The first intrusion was hornblende monzonite porphyry, the second and third were hornblende-augite monzonite porphyry, and the fourth was augite-biotite monzonite. With the possible exception of the first intrusive, each intrusive type has an extrusive equivalent.

After consolidation of the youngest monzonitic intrusive, a system of fracturing developed. Subsequent mineralizing solutions formed deposits along many of these fractures. These fractures also provided planes of weakness along which Miocene(?) limburgite magma was intruded to form many dikes throughout the area. Associated volcanic rocks of the Cieneguilla limburgite rest unconformably on an erosion surface that cuts into monzonitic intrusive and volcanic rocks along the northern edge of the area. The Cieneguilla limburgite is conformably overlain by lacustrine limestone, clay, and tuffaceous sandstone assigned to the lowermost unit of the Santa Fe group.

In the Cerrillos area, deformation during the late Pliocene Sandia uplift resulted in northward trending normal faults along the western edge of the area. The western block was dropped about 4,500 feet to form a part of the Rio Grande depression. In the eastern block, strata were tilted about 12 degrees to the east.

During Pleistocene time the Ortiz pediment was graded to the Rio Grande from the highlands of the Cerrillos, the Ortiz Mountains, and the Sangre de Cristo Range. Sand and gravel of the Ancha formation (Santa Fe group) were deposited on the pediment. Upon this gravel, in the northwestern sector of the area, Pleistocene(?) Cuerbio basalt flows were erupted.

After extrusion of the Cuerbio basalt, recurrence of normal faulting along the western edge of the area again dropped the western block, deepening the Rio Grande depression. A period of dissection of the lava- and gravel-covered pediment followed this faulting.

The Cerrillos mining district has produced zinc, lead, copper, silver, and gold from one group of deposits and turquoise from another. Most of the turquoise in this area was produced from mines at Turquoise Hill and Mt. Chalchihuitl from prehistoric time to the present. Turquoise occurs as nodules in fracture zones and in narrow veinlets which cut intrusive and volcanic rocks that have been strongly bleached by hydrothermal alteration.

The earliest metal mining in the district was by the Spaniards in the 17th century. Modern metal mining started with a boom period in 1879 but subsided after a few years. From 1909 to 1952 a production of 25,843 tons of metalliferous ore was obtained from 12 mines. This ore contained 920.68 ounces of gold, 22,187 ounces of silver, 174,894 pounds of copper, 1,379,040 pounds of lead, and 1,671,527 pounds of zinc. The Cash Entry and Tom Payne mines were the chief producers.

The primary metalliferous ores contain sphalerite, galena, chalcopyrite, and pyrite, as well as small quantities of silver and gold. Quartz, ankerite, calcite, siderite, barite, opal, and chalcedony are the most prominent gangue minerals.

Ore mineralization occurred in shear zones from a few inches to 16 feet in width, which are chiefly within the main intrusive masses. Most of the mineralized zones are traceable for a few hundred feet; a few are continuous for distances of 1,500 to 2,500 feet. Most of the ore bodies occur as shoots in the shear zones. Within these shoots the sulfides form aggregates and crustified bands or are disseminated in vein quartz or sheared wall rock.

Introduction

LOCATION AND ACCESSIBILITY OF AREA

The Cerrillos area covers about 115 square miles. The Cerrillos mining district, in the central part of the area, is about 15 miles southwest of Santa Fe, in north-central New Mexico (fig. 1). As originally organized, the Cerrillos district was restricted to the northern part of the Cerrillos ("little hills"); a second district, the Galisteo, was restricted to the southern part. In conformance with current usage, the Cerrillos district of this report includes the whole metal-mining area of the Cerrillos. Three communities lie in the area, Cerrillos, Cienega, and La Bajada.

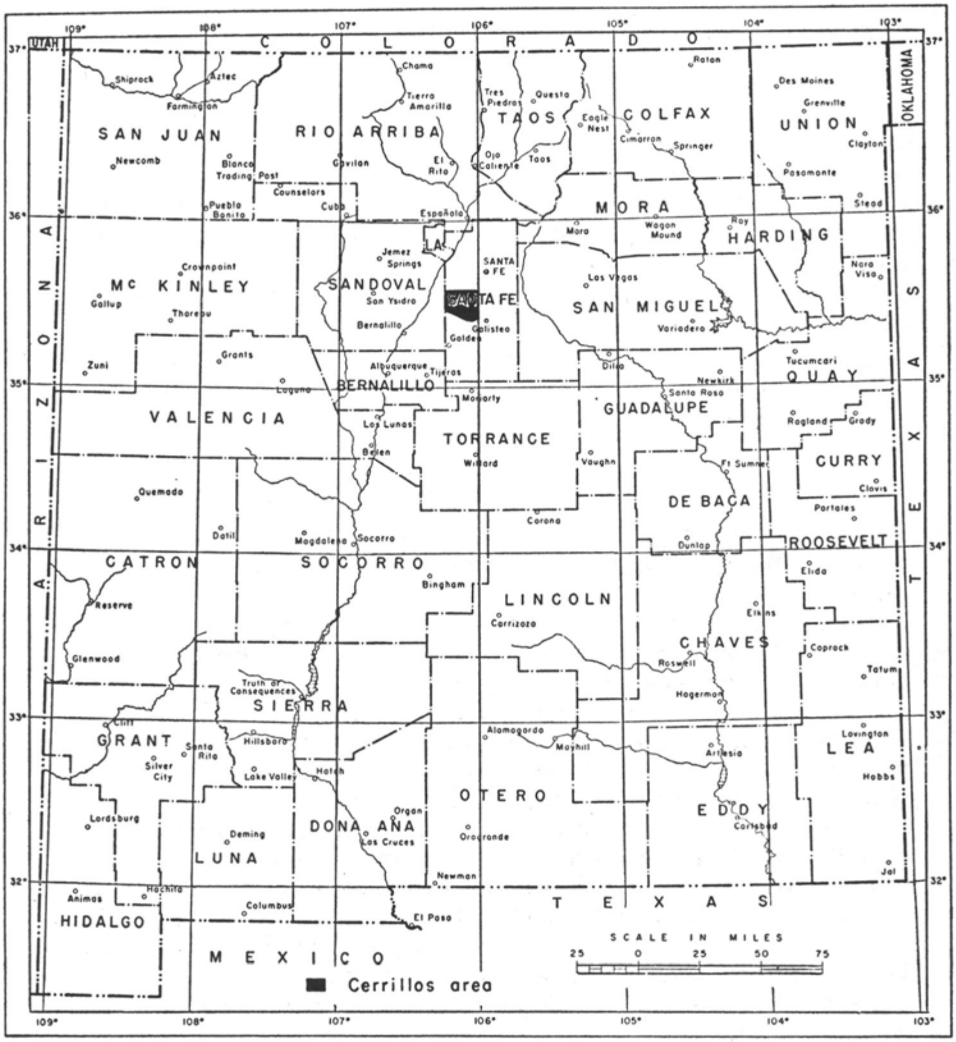
U. S. Highway 85 and State Highway 10 cross the area. Secondary and private mine and ranch roads join the main highways and permit easy access to most of the area.

SCOPE AND DIVISION OF WORK

This report was prepared by Disbrow from studies of the general geology of the area and the earlier studies by Stoll of the Cerrillos mining district.

Stoll's field work, for the U. S. Geological Survey, was started in late June 1945 and completed in early November of that year. D. M. Kinney assisted with field work at the beginning of the project; W. J. Powell assisted from July to September. The Cerrillos mining district was mapped on Soil Conservation Service aerial photographs. Control points used in compiling the data from the photographs were established with stadia and extended through the area by graphic triagulation. A larger scale planetable map was made of the north mining area. Many of the accessible mines in the district were mapped by the tape-and-compass method. After the field work was completed, Stoll (1946) prepared an open-file report on the north mining area of the Cerrillos district; he also prepared the sections of this report titled Mineral Deposits, Mine Descriptions and Economic Aspects. Information in this report concerning mine production and development for the period 1946 to 1952 was added by Disbrow.

During 1950 and 1951 Disbrow spent 4 months mapping the geology of the area in conjunction with graduate work at the University of New Mexico. Mapping was done on U. S. Soil Conservation Service aerial photographs at a scale of about 1:15,000. Data were transferred to a Soil Conservation Service planimetric base map. Classification of rock types and the relation of volcanic rocks to intrusive rocks were determined by examination of 115 thinsections.



INDEX MAP OF NEW MEXICO, SHOWING LOCATION OF THE CERRILLOS AREA.

Figure 1

Disbrow did his field work under an agreement between the University of New Mexico and the New Mexico Bureau of Mines and Mineral Resources, and he prepared the report under a cooperative agreement between the New Mexico Bureau of Mines and Mineral Resources and the U. S. Geological Survey. Although this report is a cooperative product of the U. S. Geological Survey and the New Mexico Bureau of Mines and Mineral Resources, the classification and nomenclature of the rock units used in the report differ somewhat from those of the U. S. Geological Survey.

PREVIOUS WORK

Because the Cerrillos is one of the oldest mining districts in the United States, it has attracted the attention of many geologists. A number of accounts of visits to the area during the 1800's are included in the reports of Wislizenus (1848), Blake (1858, 1859), Hayden (1869), and Silliman (1881). The first detailed report on the area was made by Johnson (1903). Lindgren (Lindgren, et al., 1910) visited the area in 1905 and described the geology and ore deposits of the hills.

The stratigraphy and paleontology of the Upper Cretaceous section southeast of the town of Cerrillos were studied and described by Lee and Knowlton (1917). The delineation of the Mesaverde, Mancos, and Dakota formations described in their Cerrillos sections was used in this report.

Stearns (1943, 1953-a, 1953-b, 1953-c) has published geologic maps and descriptions of a large area that includes the Cerrillos in its northwest sector. The Cerrillos area is included also in a preliminary oil and gas investigations report by Read and Andrews (1944) on the geology of a part of the upper Pecos River and Rio Galisteo region.

ACKNOWLEDGMENTS

Thanks are due all the mine owners and operators in the area for their cooperation and for furnishing much local information that otherwise would have been unobtainable. Particular acknowledgment is due Mr. Verne Byrne, manager of the Cerrillos Lead and Zinc Co., and Mr. George W. Carnick, chief chemist for Sierra Metals Co. Information on the mineral deposits of the area was made available by Mr. Forrest J. Sur, of the U. S. Bureau of Mines.

Drs. Parry Reiche, Stuart A. Northrop, and Vincent C. Kelley, department of geology, University of New Mexico, supplied helpful information. The senior author is indebted to Dr. Kelley for suggesting the work and for counsel on field problems and manuscript preparation. Dr. Charles E. Stearns, Harvard University, has given helpful information and criticism. A part of the expense of field work and of preparing thinsections was defrayed by the New Mexico Bureau of Mines and Mineral Resources. Drs. Eugene Callaghan, Brewster Baldwin, and Frank E. Kottlowski, of the Bureau staff, provided counsel during field work and constructive criticism of the manuscript.

The author is grateful to Joann Kellogg for the checking of references and help in the preparation of the index, and to Ernest C. Lendenmann for assistance in drafting Plate 1.

General Geology

Strata ranging in age from the Upper Triassic Chinle formation to Recent alluvium are exposed in the Cerrillos area (table 1 and pl. 1). Marine and continental sediments were deposited during repeated ad-

TABLE 1. SUMMARY OF LITHOLOGIC UNITS EXPOSED IN THE CERRILLOS AREA

ERA AND SYSTEM	SERIES	STRATIGRAPHIC UNIT	THICKNESS (FEET)	LITHOLOGY
CENOZOIC				
Quaternary	Recent	Alluvium	10-50	Soil, sand, gravel, and talus
	Pleistocene(?)	Cuerbio basalt	10-35	Basalt flows and pyroclastic rocks
	Early Pleistocene(?)	*Santa Fe group* Ancha formation	0-350	Sand, gravel, tuff, and loess
Tertiary	Middle Miocene(?)	Abiquiu(?) formation	800+	Sand, clay, and limestone; tuffaceous
	Early Miocene(?)	Cieneguilla limburgite	200-700	Limburgite intrusive, extrusive, and pyroclastic rocks, with minor amounts of sand, clay, and limestone
	Oligocene(?)	Espinaso volcanics	2,000+	Latitic flows, pyroclastic rocks, and intrusive rocks
	Oligocene(?) and Eocene	Galisteo formation	1,200-3,000	Sandstone, clay, and conglomerate, with silicified wood
MESOZOIC				
Cretaceous	Upper Cretaceous	Mesaverde formation	0-765	Sandstone and shale, with coal
		Mancos shale	2,350	Shale, with minor amounts of siltstone, sandstone, and limestone
	Upper and Lower Cretaceous	Dakota(?) formation	50-100	Sandstone, with minor amount of shale
Jurassic	Upper Jurassic	Morrison formation	850	Sandstone and shale
		Todilto limestone	86	Gypsum and limestone, with minor amount of shale
		Entrada sandstone	80	Sandstone
Triassic	Upper Triassic	Chinle formation	400+	Sandstone, shale, and limestone conglomerate (only upper 400 feet exposed)

vances and withdrawals of the Mesozoic sea. Most of the Mesozoic sequence consists of beds of sandstone and shale except for a few thin beds of limestone and a thick unit of gypsum in the Todilto limestone. Some thin beds of limestone also occur in the Mancos shale, and coal beds occur in the Mesaverde formation.

Throughout the Cenozoic era the Cerrillos area has been above sea level and was subjected to erosion and the deposition of continental material. Deposition of clastic sediments of the Galisteo formation during the Eocene and Oligocene(?) was followed by extrusions of latitic volcanic rock during the Oligocene(?) and limburgite volcanic rock in the early Miocene(?). Deposition of clastic sediments of the Santa Fe group again predominated during the Miocene(?), Pliocene(?), and Pleistocene(?). Extrusions of basalt and subsequent accumulations of alluvium have occurred in Pleistocene(?) and Recent times.

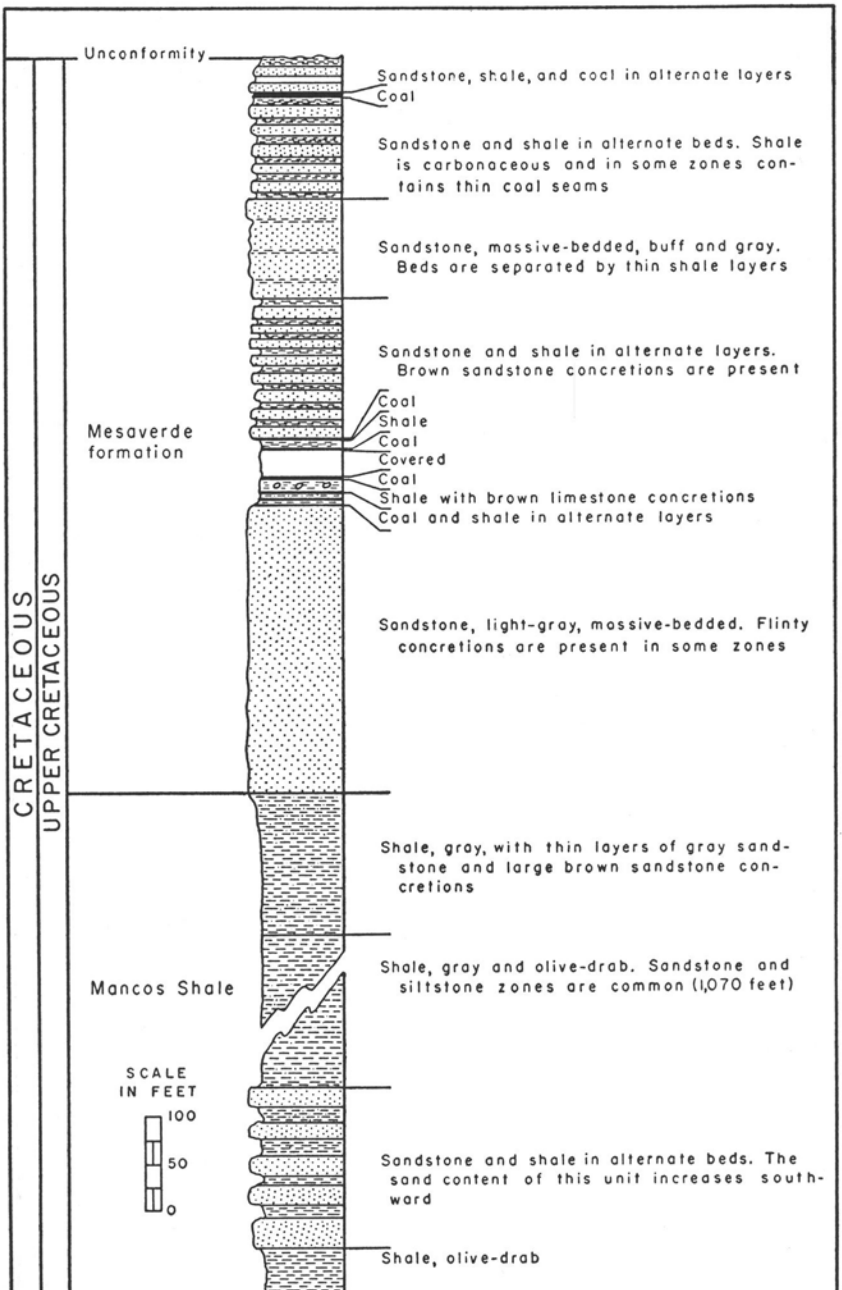
The total thickness of exposed strata ranges from 8,435 to 10,365 feet. An extension of isopachs drawn by Read and Andrews (1944, fig. 4, 6) indicates that about 2,100 feet of Pennsylvanian and Permian strata may lie beneath the Upper Triassic Chinle formation and above the Precambrian basement.

MESOZOIC ERA

Map-unit subdivisions of Mesozoic strata conform with well-known, long-established stratigraphic units in use in north-central New Mexico. A summary of the important features of these units is presented in Table 1 and in the stratigraphic column (fig. 2). A complete Mesozoic section was not measured. Data appearing in the Mesozoic stratigraphic column were, for the most part, derived from previous work done within the area or in adjacent areas. The Dakota, Todilto, and Entrada formations were measured along the southwest side of the area. The lithology of the Mesaverde formation, Mancos shale, and upper 130 feet of the Morrison formation were obtained from a section described by Lee and Knowlton (1917) along the southern edge of the area. The lithology of the lower part of the Morrison formation is from a section measured by Harrison (1949) in the Hagan basin 14 miles southwest of Cerrillos. A description of the Chinle formation was obtained from a section described by Read and Andrews (1944), near Galisteo, about 15 miles east of Cerrillos.

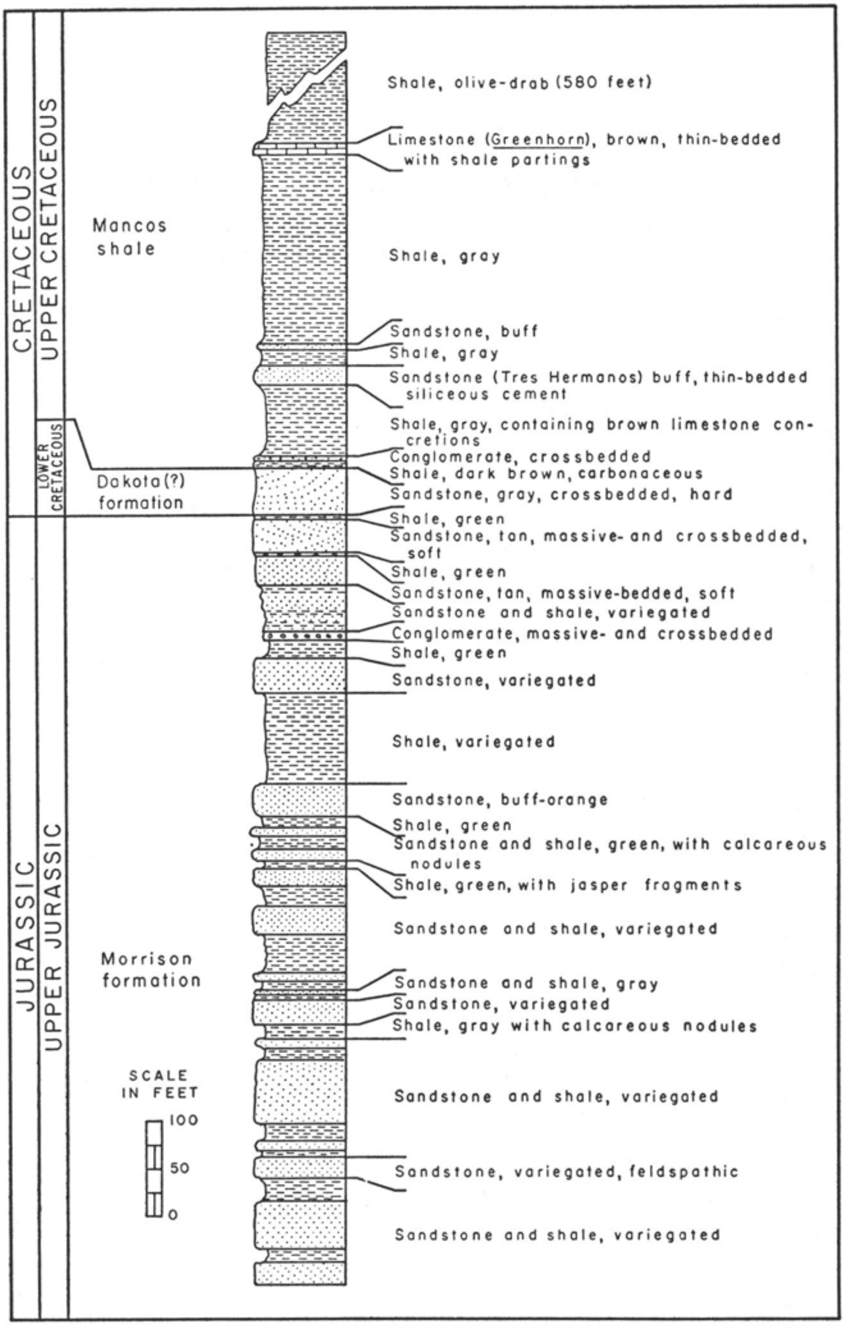
CENOZOIC ERA

In latest Cretaceous or Paleocene time, an uplift occurred in the vicinity of the present Sangre de Cristo Range. Contemporaneous with and continuing after the uplift, there was erosion of the elevated area. Detrital material was deposited with but slight unconformity on underlying Upper Cretaceous sediments. In the region of the San Juan Basin



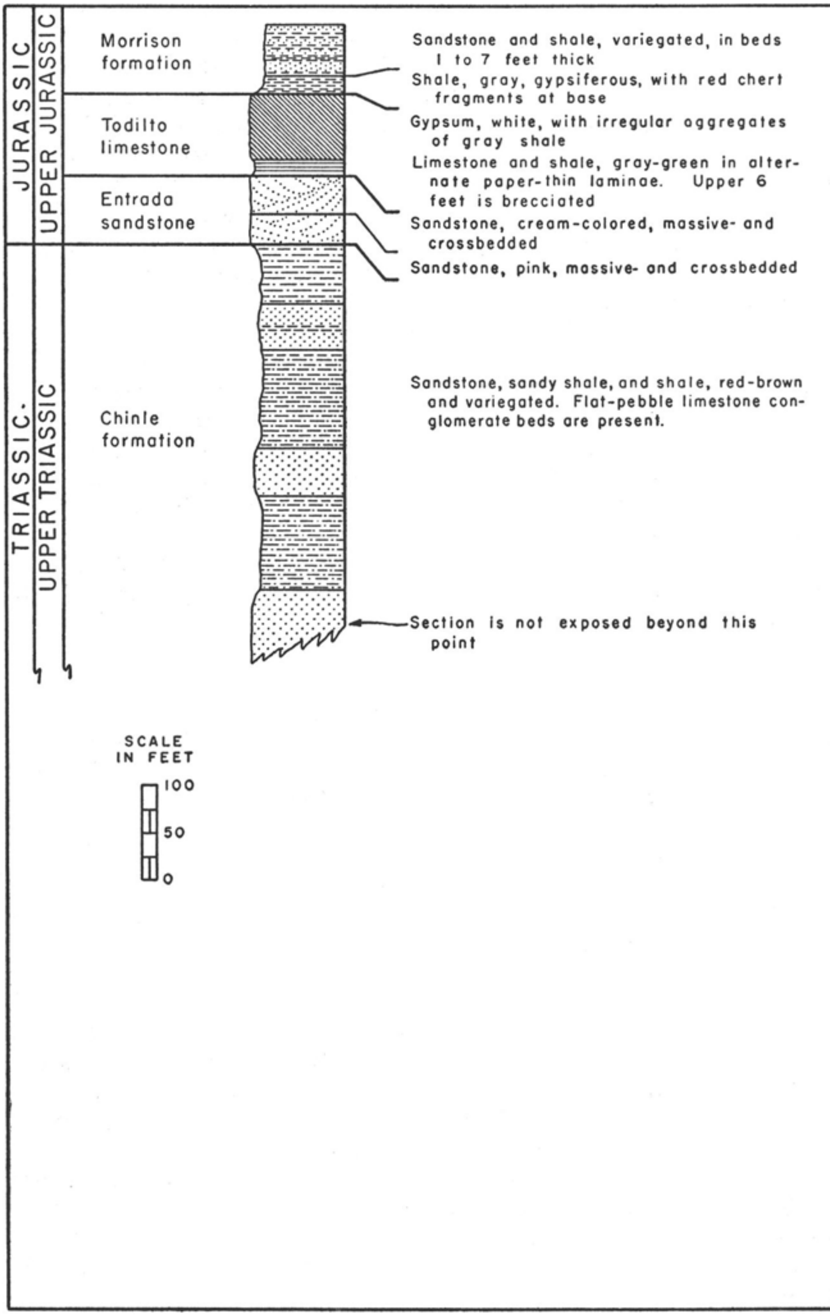
COLUMNAR SECTION OF MESOZOIC STRATA.

Figure 2



COLUMNAR SECTION OF MESOZOIC STRATA.

Figure 2 (continued)



COLUMNAR SECTION OF MESOZOIC STRATA.

Figure 2 (continued)

to the west, the uppermost Cretaceous and, with more certainty, the Paleocene strata rest upon this erosion surface, overlapping eastward onto progressively older formations (Silver, 1950, p. 112).

Although evidence of a thinning and possible pinch-out of Paleocene formations against an eastern highland has not been recorded, strata of this age may be absent in the Hagan-Cerrillos-Galisteo region. In this region the Galisteo formation of Eocene and Oligocene(?) age rests upon an erosion surface which in the direction of the Sangre de Cristo Range bevels progressively older beds. Possibly the slight hiatus at the base of the Tertiary rocks in the San Juan Basin was more extensive in time progressively toward the east. In the Cerrillos area the period of erosion may represent the whole of Paleocene and possibly part of Eocene time.

The deposition of Galisteo clastic sediments of Eocene and Oligocene(?) age was followed by the emplacement of igneous masses during Oligocene(?) and early Miocene(?) time. Associated with these intrusives are a series of extrusives that have been subdivided into the Espinaso volcanics and Cieneguilla limburgite. The Cieneguilla limburgite is conformably overlain by tuffaceous sand, clay, and limestone of the Miocene(?) Abiquiu(?) formation (Santa Fe group).

The names Espinaso volcanics, Cieneguilla limburgite, Abiquiu(?) formation, and Cuerbio basalt were assigned to lithologic units by Stearns (1943, 1953-a, 1953-b).

GALISTEO FORMATION

The term "Gallisteo [sic] sand group" was applied by Hayden (1869) to a unit of sandstone, clay, and conglomerate that overlies Upper Cretaceous strata a few miles southwest of Santa Fe. The name of this unit was changed to Galisteo formation by subsequent workers in the region. In the Cerrillos area strata lying between the erosion surface that cuts Upper Cretaceous strata and the top of the first massive sandstone beneath the Espinaso volcanics have been placed in the Galisteo formation. The surface underlain by the Galisteo formation consists of sandstone and conglomerate ridges and clay swales. Near intrusive masses, where the beds are pushed up vertically, the sandstone beds stand out as ribs.

According to Stearns (1943, p. 305), sandstone and conglomerate comprise two-thirds of the formation. Sandstone beds are gray, white, buff, yellow, brown, pink, or red. The thicker units are commonly cross-bedded and cemented by calcium carbonate. Sand grains range in size from medium to coarse and are composed mainly of quartz, with lesser amounts of feldspar and lithic material. Channel fillings of pebble and cobble conglomerate are common in the sandstone. These coarse elastics consist of subangular to well-rounded pieces of chert, chalcedony, quartz, quartzite, granite, schist, gneiss, porphyry, and limestone (Stearns, 1943, p. 305).

Petrified wood occurs in many of the sandstone beds. Some logs have a battered appearance similar to that of driftwood, suggesting that the original trees were transported a considerable distance, beached, covered with sand, and later silicified.

Stearns (1943, p. 307) reported that about one-third of the formation is composed of clay. These clays are colored vivid reds, purples, and greens; brown and gray clays are also present. Locally the clay may be sandy or gypsiferous or may contain calcareous nodules.

The formation ranges from 1,200 to 3,000 feet in thickness. Almost all the sediments of the Galisteo formation are clastics. Among these clastics are lithic fragments similar to Precambrian and Pennsylvanian rocks now exposed in the Sangre de Cristo Range. The source of this material and of the finer grained classic rocks was probably a highland in the vicinity of the Sangre de Cristo Range. Much of the detritus from this source area was carried by streams of considerable volume and gradient to the Galisteo basin, where it was deposited in river channels, flood plains, and temporary lakes (Stearns, 1943, p. 312). The presence of pine and hardwood logs throughout the section, together with titanothere bones, indicates that the prevailing climate was warm and at least seasonally humid (Stearns, 1943, p. 313).

Aside from petrified wood, dated as Upper Cretaceous or younger, all the fossil evidence used by Stearns (1953-a, p. 467) to date the Galisteo formation as late Eocene was collected not more than 200 feet below the top of the formation. From the massive uppermost sandstone at Sweet's ranch, east of Cerrillos, Dr. T. E. White has identified *Uintacyon* sp. and *Teleodus* sp. (Stearns, 1943, p. 310). Romer (1947, p. 614, 619) dates the *Uintacyon* sp. as Eocene and *Teleodus* sp. as Eocene-Oligocene. Definite Oligocene fossils that were collected from bentonite clay about 25 feet above the top of the Galisteo formation will be discussed later. Fossil evidence indicates that deposition of the Galisteo formation terminated in late Eocene or possibly early Oligocene time.'

The similarity in lithology and stratigraphic position of the Eocene San Jose formation of the northeastern side of the San Juan Basin (Simpson, 1950, p. 78) and the El Rito formation near Abiquiu, New Mexico (Smith, 1938, p. 940), suggests that these units may be correlative with the Galisteo formation of the Cerrillos area.

ESPINASO VOLCANICS AND ASSOCIATED INTRUSIVE ROCKS

Throughout much of Oligocene time the Cerrillos and adjacent areas were the *site* of intense intrusive and extrusive igneous activity. The sequence of volcanic rocks that were extruded during this period of volcanism was named the Espinaso volcanics by Kirk Bryan in an

1. Robinson (1957) collected a molar of *Coryphodon* 700 feet above the base of the Galisteo formation, 2 miles northeast of Cerrillos. *Coryphodon* is of Wasatchian (lower Eocene) age.

unpublished manuscript on the geology and geomorphology of the Santo Domingo valley, just south and west of the Cerrillos area (Stearns, 1943, p. 309). In the type locality along Arroyo Pinovetito, 11 miles southwest of Cerrillos, Stearns (1953-b, p. 422) measured a thickness of 1,450 feet of water-laid tuff, tuff-breccia, and volcanic conglomerate. In the Cerrillos area the Espinaso comprises a sequence of more than 2,000 feet of la titic tuffs, tuff-breccias, and flows that unconformably overlie the uppermost massive sandstone of the Galisteo formation and that are unconformably overlain by the basal limburgite flow or tuff of the Cieneguilla limburgite. Associated with the Espinaso volcanics in the Cerrillos area are several intrusive masses that are chiefly monzonitic in composition.

Exposures of the Espinaso volcanics occur along the eastern edge of the Cerrillos, in several areas adjacent to Cerro Seguro, in the canyon of the Santa Fe River, and in a much faulted area just to the south of the mouth of this canyon. For the most part, areas underlain by these rocks were beveled during Pleistocene(?) pedimentation. Subsequent erosion of the beveled volcanic rocks has yielded a series of ridges and valleys formed by resistant flows and flow breccias and less resistant tuffs and tuff-breccias. The larger intrusive masses associated with the volcanic rocks form the steep-sided Cerrillos, which rise several hundred feet above the pediment in the center of the southern half of the mapped area and, near Cienega, form Cerro Seguro and Las Tetillitas.

Four major periods of igneous activity during Espinaso time are recognized in the Cerrillos area. For convenience in the text and on the map, the first and oldest period of igneous activity is designated T_1 and the successively younger periods are designated T_2, T_3, and T_4. In the T_1 period a hornblende monzonite porphyry mass was emplaced, mainly in the southern half of the Cerrillos. No extrusive rocks can be assigned with certainty to the T_1 period. During the T_2 and T_3 periods hornblende-augite monzonite porphyry intrusive rocks and hornblendeaugite latite porphyry volcanic rocks were emplaced. Augite-biotite monzonite porphyry of the T_4 period formed many sills, dikes, stocks, and plugs in older sedimentary and igneous rocks, chiefly in the northern half of the area. Augite-biotite latite porphyry pyroclastic rocks are also associated with this igneous period.

Rocks of all four periods have, for the most part, a monzonitic composition and contain either hornblende or augite or both of these minerals, although the size of crystals and the amount of these minerals differ with each period. Intrusive relationships were observed between the younger and older rocks of all four igneous periods. However, because intrusive rocks of the T_1, T_2, and T_3 periods are difficult to distinguish readily in the field, these intrusive masses were mapped as a single unit. The extrusive rocks associated with the first three periods were mapped separately only in the relatively undeformed area east of the Cerrillos. Intrusive rocks of the **T_4** period can be distinguished readily in the field from those of the earlier periods and therefore were mapped separately. Extrusive rocks of the T4 period were observed at the top of the Espinaso volcanics in the canyon of the Santa Fe River, 11/2 miles east-southeast of La Bajada. The presence of faults and cover in this area prohibited a map separation of these rocks from those of the earlier periods.

Igneous Period T_1

Intrusive bodies of hornblende monzonite porphyry of the T_1 period occur throughout the major area of intrusion which forms the core of the Cerrillos (pl. 1). However, within the major area of intrusion, about 90 percent of the T_1 monzonite porphyry crops out in the southern half of the area, where it forms a stock or plug with associated dikes, tongue laccoliths, and sills. At the surface this stock penetrates and deforms strata from the Upper Jurassic Morrison formation to the Galisteo formation of Eocene and Oligocene(?) age. The main mass of magma, however, was emplaced in relatively soft Mancos shale.

Contact metamorphism of this shale was slight; it resulted generally in a hornstone zone ranging from a few inches to 3 feet in thickness. Metamorphism was more intense in shale and sandstone inclusions.

Petrographic examination of many specimens of this intrusive shows that, except for degree of alteration, the composition and grain size of the rock are nearly constant throughout the area. A typical specimen from a locality 1 mile northwest of Cerrillos is a gray porphyry, in which equant plagioclase and elongate black hornblende phenocrysts lie in a dark aphanitic groundmass. In thinsection the rock is seen to be holocrystalline, with a grain size ranging from microcrystalline to phanerocrystalline. The rock contains the following estimated percentages of minerals:

	Percent
Oligoclase-andesine, subhedral zoned grains, 0.5-2 mm long	33
Orthoclase, microcrystalline anhedral grains interstitial to larger phenocrysts	35
Quartz, microcrystalline anhedral grains in groundmass	10
Hornblende, yellow-green euhedral to subhedral phenocrysts, 0.5-1 mm long	15
Augite pale-green euhedral to subhedral grains, 0.1-0.5 mm long	0-2
Sphene and apatite, small euhedral grains	Trace
Magnetite, irregular blebs 0.1 mm in diameter, in groundmass	5
Total	100

Some degree of postsolidification alteration was observed throughout the hornblende monzonite porphyry. Chloritization of the edges of the hornblende phenocrysts and sericitization of feldspars along edges and cleavage planes increase in intensity in the direction of younger igneous bodies which intrude this monzonite porphyry. Near the contact with these younger intrusive masses, the host rock in many places has been completely bleached, suggesting a removal of iron from the hornblende and destruction of feldspar.

Intrusion of hornblende monzonite porphyry, on the northeastern side of the stock, into the basal beds of the Galisteo formation indicates that its upper limit of penetration reached within about 2,500 feet of the surface on the flank of the stock. Inasmuch as no pyroclastic material of similar composition was observed locally, it seems improbable that the T_1 intrusion breached the surface.

There was evidently erosion of both the uplifted sedimentary rocks and the T_1 intrusive rocks before the T2 period. In the faulted area 2 miles southeast of La Bajada, the top of the Galisteo formation contains thick- to massive-bedded arkosic sandstone with pebble lenses in which there are small angular fragments of petrified wood and pebbles of hornblende monzonite porphyry. North of Sweet's ranch an accumulation of sandstone blocks in a tuffaceous clay occurs in a zone at the base of the volcanic rocks.

In the critical area adjacent to Grand Central Mountain (pl. 1), hydrothermal alteration and brecciation during the emplacement of T4 intrusive masses have destroyed the textural and structural features of the rock. Consequently, it was impossible during the field study to prove the presence or absence of pre-T_2 detritus overlapping the T_1 intrusive.

Igneous Period T2

Erosion of the elevated area in the center of the hills was interrupted by intrusion of T2 hornblende-augite monzonite porphyry and associated extrusion of a thick sequence of volcanic rocks. Although T2 intrusive bodies are not mapped separately from the earlier intrusive bodies, this intrusive relationship was noted at several places in the southeastern part of the hills. Where fresh, the intrusive rock is a gray porphyry with phenocrysts of augite, hornblende, and plagioclase feldspar in a gray aphanitic groundmass. In thinsection the rock appears holocrystalline and contains the following estimated percentages of minerals:

	Percent
Oligoclase-andesine, subhedral zoned phenocrysts, 0.2-1 mm long	**40**
Orthoclase, in microgranular groundmass	**35**
Hornblende, yellow-green euhedral and subhedral phenocrysts, 0.5-2 mm long	**12**
Augite, pale-green euhedral and subhedral phenocrysts, 0.5-2 mm long	**8**
Magnetite, blebs 0.05-0.1 mm in diameter in groundmass	5
Sphene, yellow euhedral phenocrysts	**Trace**
Total	**100**

During the T_2 period of igneous activity, hornblende-augite latite porphyry volcanic rocks were poured out on an erosion surface which was irregular near the intrusive center and which became more smooth away from the center. At a distance of about 11,000 feet from the margins of the eroded stock of the first intrusive stage, these volcanic beds appear to be conformable with the underlying Galisteo formation strata. Volcanic rocks of the **T_2** period can be subdivided into three distinct litho-logic units: a basal flow, a unit of soft tuff, and an upper unit of red tuff-breccia.

The basal flow of this volcanic sequence was observed 2,000 feet north of the San Marcos reservoir (pl. 1). From an approximate thickness of 300 feet along its southwestern edge, it thins northeastward to about 50 feet, within a distance of 6,000 feet.

Except for the formation of brown basaltic hornblende from green hornblende, minerals in this latite porphyry flow are similar to those of the intrusive rock of this period. Iron oxide rims on the basaltic hornblende are thinnest at the base (southwestern side) of the flow. The gray rock is progressively redder upward in the flow. At the top of the flow (northeastern side) the rock is a reddish purple, the same color as much of the pyroclastic material adjacent to it.

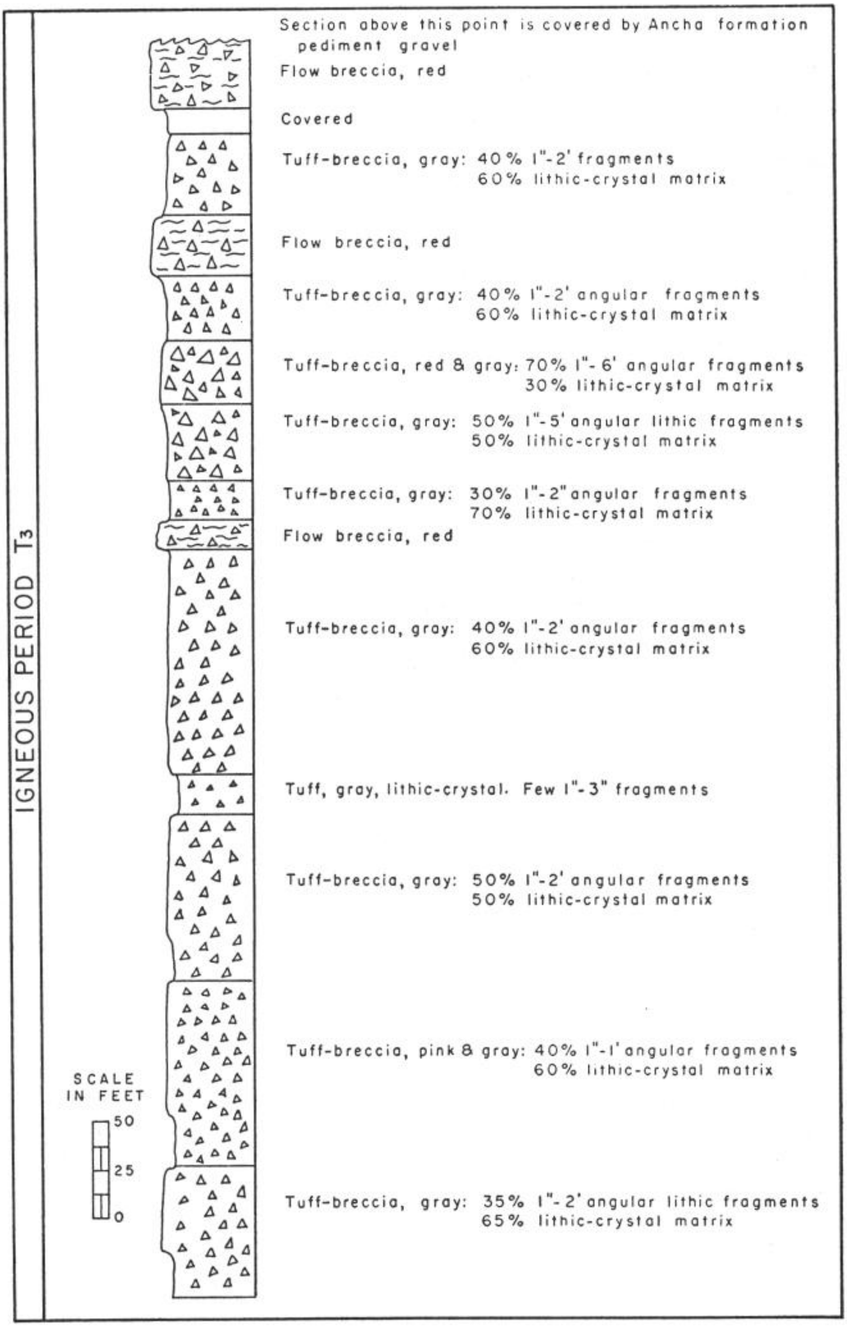
In thinsection the color change upward in the flow appears to be caused by the presence of hematite dust in the groundmass. This hematite may have been derived from oxidation of mafic minerals. Opaque iron oxide rims on basaltic hornblende phenocrysts increase in thickness upward in the flow.

Other outcrops of this basal flow were observed three-fourths of a mile southeast of Rocky Butte and 1 mile north of Sweet's ranch. In these outcrops the flow is about 20 feet thick and has a red scoriaceous top. These outcrops probably represent tongues of lava from a flow which decreased in size away from a source in the southern part of the hills.

Where this flow is present, it lies at the base of a soft tuff unit that ranges from 50 to 100 feet in thickness. The unit consists of beds of red, green, and gray lithic-crystal tuff. This tuff both is interbedded with and forms the matrix for layers of latite porphyry pebbles and cobbles (fig. 3).

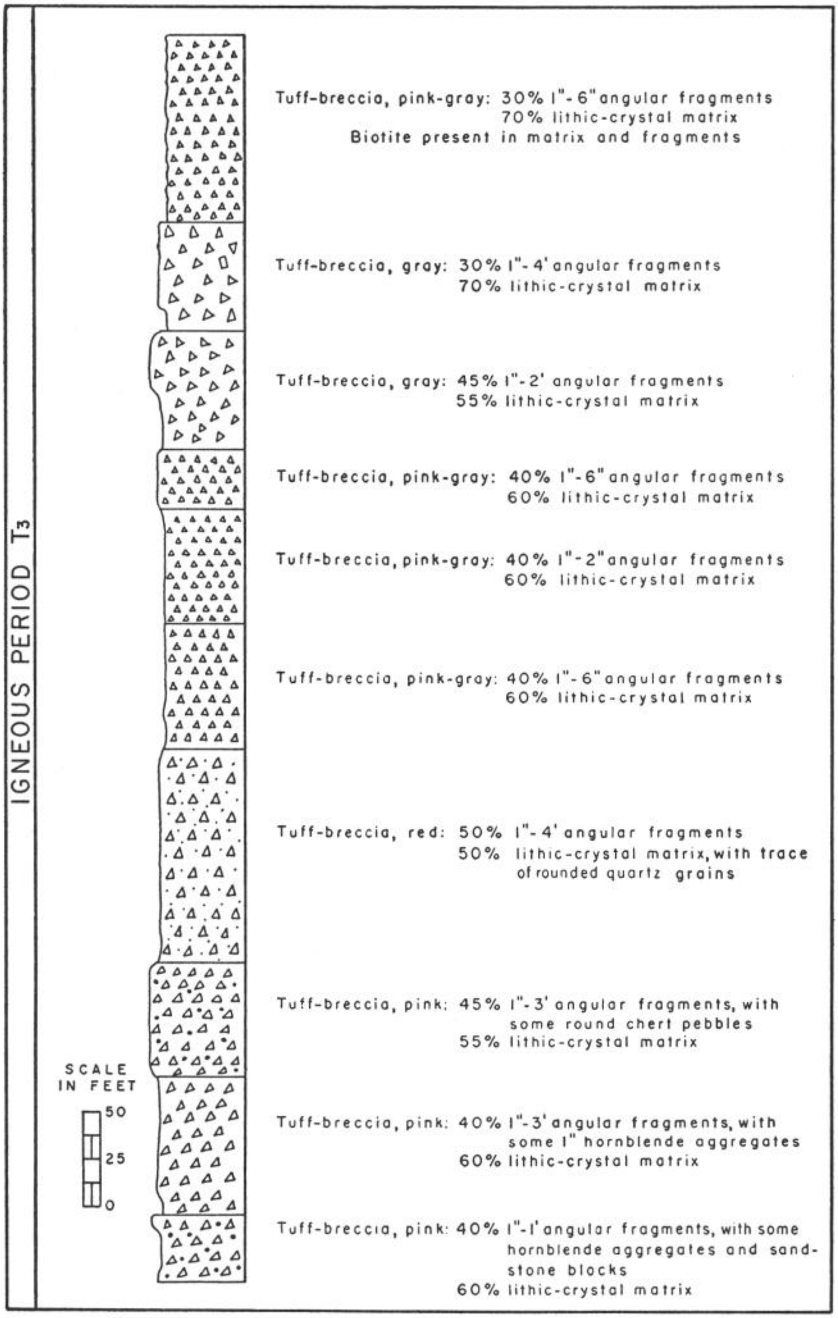
Above the soft tuff unit is a series of beds of red tuff-breccia. In general the material in this unit is moderately well bedded and moderately well cemented. Fragments in the tuff-breccia are angular to subangular and range from an inch or less to about 2 feet in diameter. Most of the fragments are of lathe porphyry similar in appearance to the basal flow. About 130 feet above the base of this unit, fragments of lavender hornblende-augite latite porphyry appear. In this rock the pale-green augite phenocrysts form distinctive radial clusters.

Blocks of sandstone and pebbles of chert are present in minor amounts in the lower 110 feet of the tuff-breccia unit. This material may have been eroded from Galisteo that was uplifted during the T_1 period of intrusion.



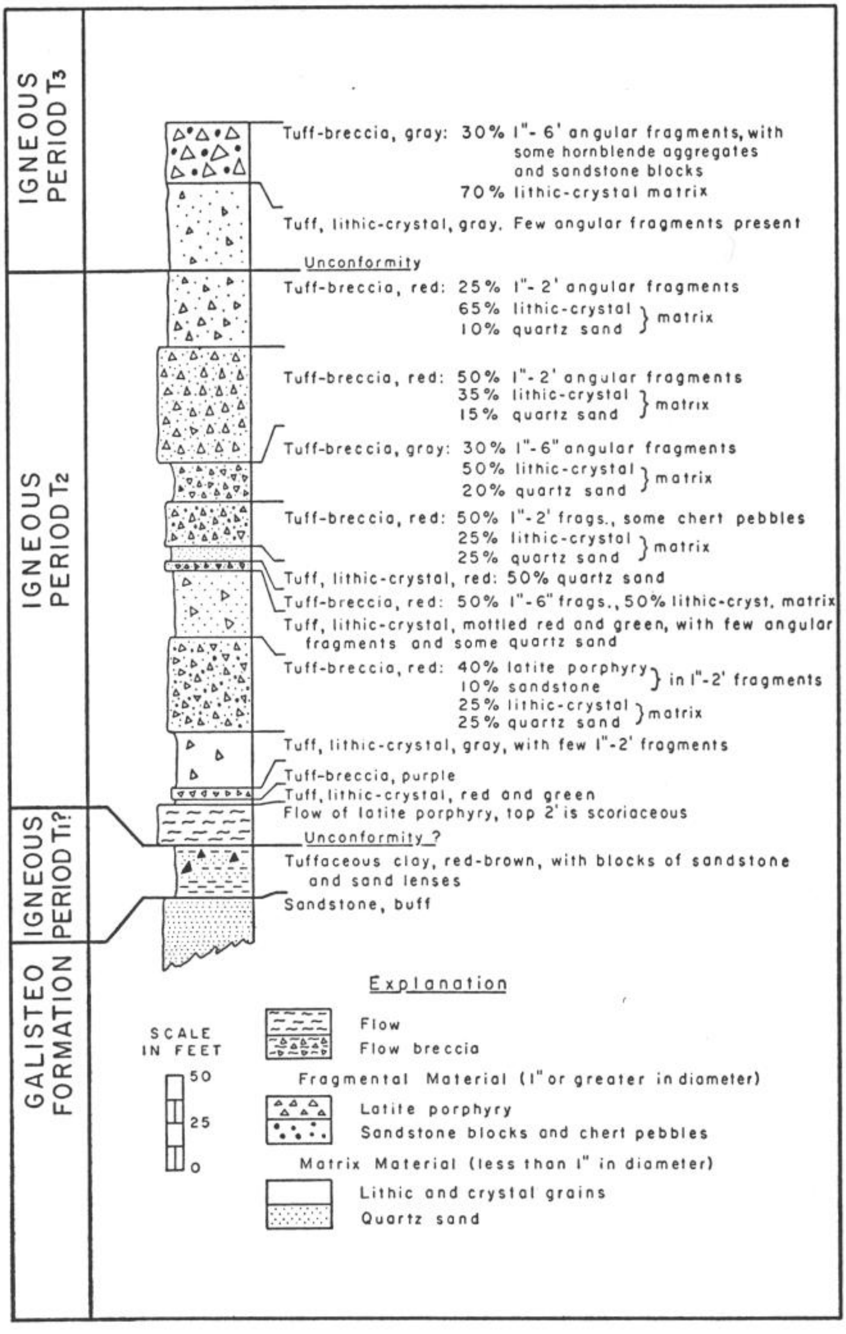
COLUMNAR SECTION OF ESPINASO VOLCANICS NEAR SWEET'S RANCH.

Figure 3



COLUMNAR SECTION OF ESPINASO VOLCANICS NEAR SWEET'S RANCH.

Figure 3 (continued)



COLUMNAR SECTION OF ESPINASO VOLCANICS NEAR SWEET'S RANCH.

Figure 3 (continued)

The matrix comprises 50 to 80 percent of the tuff-breccia unit. In hand specimen the matrix is red. Macroscopically one can see gray lithic fragments, crystal fragments, and rounded quartz grains bonded by a red aphanitic material.

A thinsection of the matrix from 20 feet below the top of the tuff-breccia unit west of Sweet's ranch contained the following material:

	Percent
Rock fragments, hornblende-augite latite porphry, 0.3-2 mm in diameter	20
Hornblende, green to brown (basaltic) crystals 0.1-0.4 mm long	10
Augite, green crystals, 0.1-0.4 mm long	5
Quartz, rounded to subrounded grains, 0.1-0.3 mm in diameter	15
Andesine, crystals, 0.1.1 mm long	25
Fine-grained material, composed of small feldspar grains, clay, and hematite	25
Total	100

In general, tuff-breccias of the T_2 period can be distinguished from tuff-breccias of subsequent stages by the following features:

1. The strong hematite-red color.
2. Moderately developed bedding.
3. An abundance of rounded quartz grains in the matrix and the presence of sandstone blocks and rounded chert pebbles among the larger fragments.
4. Dark minerals in fragments. In fragments of this stage, hornblende crystals are 1-2 mm long, and augite is about 1 mm long. Both can be recognized in hand specimen. In fragments of the T_3 period, hornblende is 1-3 mm long but augite is less than 0.5 mm long and therefore difficult to observe in hand specimen. In fragments of the T_4 period, biotite and augite form recognizable dark minerals, but hornblende is rare or absent.

Igneous Period T_3

A series of tuffs, tuff-breccias, and flow breccias were deposited in the Cerrillos area during the second major extrusion of hornblende-augite latite porphyry. T_3 volcanic rocks crop out 11/2 miles southeast, as well as 11/2 miles east-southeast of La Bajada, near Cienega, and on the northeastern side of the Cerrillos. T_3 volcanic rocks were mapped separately east of Sweet's ranch in the southeast corner of the area (pl. 1). Several small T_3 intrusive bodies were noted but not mapped separately from the large T_1 intrusive mass.

The volcanic rocks, which comprise the major part of T_3 rocks, are usually light gray or light pink. They are soft and easily eroded, and were beveled during Pleistocene pedimentation. In an area of slight deformation east of Sweet's ranch, a partial section (fig. 3) of these volcanic rocks, 1,370 feet thick, was measured along an arroyo; an additional unknown thickness of the upper part of this unit is covered by gravels of the Ancha formation. In this arroyo a bed of light-gray lithiccrystal tuff rests on a channeled erosion surface cut into the tuff-breccia unit of the **T**2 volcanic rocks. This T3 tuff is composed of hornblende, augite, and plagioclase crystals and small lithic fragments. A few larger fragments, generally less than 1 foot in diameter, are similar in composition to those in the underlying **T2** volcanic rocks and may have been derived from them. Attitudes of beds of both periods are conformable.

Above the basal tuff is a series of tuff-breccias containing fragments ranging from **1** inch to 6 feet in maximum diameter. A lack of sorting and bedding is indicated by a jumble of blocks of hornblende-augite latite of all sizes within the tuff-breccia units. Fragmental material is bonded by a light-gray lithic crystal matrix. A few sandstone fragments and rounded quartz grains are present in the lower 300 feet of the section.

Most of the fragmental material in the tuff-breccias is a light-gray latite porphyry. In hand specimen phenocrysts of elongate black or hematite-rimmed hornblende and white plagioclase are visible in a gray aphanitic groundmass. Ball-like aggregates of hornblende crystals a quarter to one inch in diameter are common. In a thinsection of a specimen from the lowermost tuff-breccia the following percentages of minerals were estimated:

	Percent
Oligoclase-andesine, subhedral zoned phenocrysts, 0.1-2 mm long	35
Basaltic hornblende, brown and green euhedral to badly corroded anhedral phenocrysts, 0.5-2 mm long. The large phenocrysts commonly have inner and outer iron oxide resorption rims	15
Augite, pale-green euhedral to corroded anhedral phenocrysts, 0.05-0.5 mm long	10
Groundmass, containing microcrysts of feldspar, with an index of refraction lower than that of balsam, and also magnetite blebs	40
Total	100

At 480 feet above the base of the T3 volcanic rocks, fragments of dense lavender latite porphyry appear in the tuff-breccias. This material, in part vesicular, becomes more abundant upward in the section. In the upper 300 feet of the section there are three flow breccias of this rock. In hand specimen, rock from the uppermost flow breccia is a dense, reddish-purple porphyry.

In thinsection, the rock is holocrystalline, has a porphyritic texture, and contains:

	Percent
Oligoclase-andesine, subhedral zoned and corroded phenocrysts, 0.2-3 mm long	35
Hornblende, green and brown euhedral to subhedral corroded phenocrysts, 0.2-2 mm long. Single resorption rims of iron oxide appear on a fewphenocrysts	20

Biotite and augite, subhedral, corroded phenocrysts about 0.1 mm in maximum dimension .... Trace
Groundmass, microcrystalline, granular with an index of refraction less than that of balsam. Much iron oxide dust is present. Groundmass may be devitrified glass 45
Total 100

Biotite and basaltic hornblende are the common dark minerals in fragments of the tuff-breccia bed from 630 to 725 feet above the base of the section.

All the tuff-breccia has a lithic-crystal matrix. The ratio of lithic to crystal material and the proportions of various types of crystal material vary from bed to bed. In general the matrix has the same composition as the fragmental material in the tuff-breccia in which it occurs.

In the section of T_3 period volcanic rocks there is a progressive decrease in both size and quantity of augite and an increase in size and quantity of hornblende upward from the base of the section.

Igneous Period T_4

The T_4 period of igneous activity is represented by a large number of stocks or plugs, sills, dikes, and related volcanic rocks of indeterminate thickness. T_4 rocks are chiefly monzonitic in composition and contain augite and biotite as the main mafic minerals.

Intruded masses of augite-biotite monzonite form most of the high hills that protrude from the Ortiz pediment in the Cerrillos area. As many as 17 storklike or pluglike remnants were mapped. A system of dikes radiates from the main intrusive mass in the northern end of the Cerrillos. These dikes form great rock walls in the more easily eroded Upper Cretaceous and Upper Jurassic sedimentary rocks in the southwest corner of the map area.

Dikes of this rock penetrate intrusive bodies of the earlier periods and north of Sweet's ranch (pl. 1), intrude T_3 volcanic rocks.

Four types of intrusive rock having similar mineral constituents in varying proportions and textures have been placed in this period of igneous activity. These are:

Type 1. Augite-biotite monzonite (shown as Ti_4 on pl. 1).

This monzonite forms the intrusive bodies in the central part of the Cerrillos. The largest of these bodies occupies most of the area in the northern half of the hills. Smaller intrusive bodies underlie Grand Central Mountain, Franklin Hill, Mt. McKenzie, and part of Turquoise Hill. A few other minor bodies were mapped on the northeastern side of the hills.

In hand specimen the augite-biotite monzonite is dark gray and weathers to light gray. It has a porphyritic texture with phenocrysts of mafic minerals and plagioclase in a finer grained, light-gray ground-mass.

In thinsection the rock appears holocrystalline and often entirely phanerocrystalline. The type and estimated amounts of minerals present are:

	Percent
Andesine, subhedral phenocrysts, 1-5 mm long. Many of the phenocrysts are embayed and rimmed by orthoclase	45
Orthoclase, interstitial anhedral often poikilitically including andesine and mafic minerals	40
Augite, green euhedral to corroded subhedral phenocrysts, 1-5 mm long	10
Biotite, brown anhedral shreds and embayed fragments of phenocrysts, 0.5-1.5 mm in diameter	5
Sphene, yellow euhedral phenocrysts	Trace
Total	100

The estimated percentages of minerals given above are typical of most of the augite-biotite monzonite. Local variations in composition are common. The andesite-gabbro phase described by Johnson (1903, p. 79-81) at Mt. McKenzie was observed in thinsection. In this orthoclase-deficient phase the ratio of mafic minerals to feldspar is about twice as great as in the typical specimen described above. This ratio suggests differentiation within the magma with a removal of the constituent of orthoclase. Such differentiation may have been the origin of orthoclase-rich (syenite porphyry) rocks described as type 4.

Type 2. Augite-biotite monzonite porphyry (Ti_{4a}, pl. 1).

This rock forms intrusive bodies north and northeast of the Cerrillos. The largest of these bodies underlies Rocky Butte, Cerro Seguro, and Las Tetillitas.

In hand specimen the rock is a light-gray porphyry with plagioclase, augite, and biotite phenocrysts in a light-gray aphanitic groundmass. In thinsection mineral types and percentages are the same as described in type 1. In this rock, however, the orthoclase occurs in a microcrystalline groundmass and andesine is more heavily zoned and fractured. Augite is less corroded.

Most of the intrusions of this rock type were into volcanic rock of the preceding igneous periods and some of them reached the surface. Solidification at shallow depths is responsible for the formation of the microcrystalline groundmass.

Type 3. Large andesine augite-biotite monzonite porphyry (Ti_{4b}, pl. 1).

A large number of irregular dikes and sills composed of rock of type 3 intrude volcanic rocks of preceding periods northeast and east of Grand Central Mountain. A small plug with radial dikes intrudes Mancos shale and hornblende monzonite porphyry south of Franklin Hill.

In hand specimen the rock is a gray porphyry with augite phenocrysts; books and shreds of biotite; and quarter- to half-inch plates of andesine in a granular gray groundmass. This rock differs from type 1 only in texture.

Type 4. Augite-biotite syenite-trachyte porphyry (Ti_{4e}, pl. 1).

Several intrusive bodies of syenite porphyry were mapped on the border of the large augite-biotite monzonite stock west and south of the Black Hornet shaft.

In hand specimen this rock is a gray porphyry with tabular gray orthoclase phenocrysts ½ to 1½ inches long set in a granular light-gray groundmass. In thinsection the groundmass is a hypidiomorphic aggregate of orthoclase and oligoclase with accessory biotite and opaque oxides.

Trachyte porphyry crops out in the vicinity of Middle Hill on the east side of the Cerrillos. A small dike of this rock intrudes Mancos shale on the south side of Turquoise Hill. Two red-brown trachyte dikes intrude volcanic rocks in the arroyo 1¼ miles north of the San Marcos Arroyo bridge on the east side of the hills. Orthoclase and biotite phenocrysts are set in a very fine-grained groundmass composed chiefly of orthoclase with minor amounts of augite, biotite, and plagioclase.

Volcanic rocks of the $\mathbf{T_4}$ period are exposed at the top of the section near the mouth of the canyon 1½ miles east-southeast of La Bajada and 1½ miles southeast of La Bajada. At these places gray and brown tuff, tuff-breccia, and volcanic conglomerate conformably overlie volcanic strata of the preceding period.

Fragmental material is chiefly gray and red-brown augite-biotite latite porphyry similar in composition to the first three types of $\mathbf{T_4}$ rocks described above.

From the nature of the strata that comprise the Espinaso volcanics of Stearns (1943), one would expect rapid horizontal changes in facies as well as differences in relationship with overlying and underlying formations. Comparison of the volcanic rocks in the type locality with those of the Cerrillos area shows these features:

1. Boulders and cobbles are subrounded. In the Cerrillos area they are angular to subangular.
2. Size of fragments is, in general, smaller and the degree of sorting is much greater than in the Cerrillos.
3. Boulders of lithic-crystal tuff containing distinctive aggregates of hornblende crystals and pebbles of altered sediments are found in increasing abundance upward from the base of the section at Arroyo Pinovetito. Tuff containing similar hornblende aggregates is found in the upper part of the volcanic rocks exposed east of the Cerrillos. Altered material similar to the pebbles above can be found in place in the Cerrillos, where the alteration is attributed to igneous intrusion associated with the eruption of the pyroclastics that comprise the upper part of Espinaso volcanics.

4. The Espinaso volcanics rest with apparent conformity between the underlying Galisteo and overlying Abiquiu(?) formations. Contacts between these formations are gradational. In the Cerrillos unconformities occur at the base, within, and at the top of the volcanic rocks.

From a bentonite bed described by Stearns (1943, p. 310) at the base of the volcanic rocks in Arroyo Pinovetito, Mr. D. F. Toomey, a student at the University of New Mexico (written communication), collected titanothere bones and teeth. In this material Dr. T. E. White, of Harvard University, has identified parts of *Brontothere* sp., an early Oligocene form, and *Teleodus* sp., an Eocene to Oligocene transition form also found in the uppermost bed of the Galisteo formation at Sweet's ranch (Stearns, 1943, p. 310). The presence of bentonite with these fossils indicates that the igneous activity associated with the Espinaso volcanics began in early Oligocene time. This volcanic unit is unconformably overlain by rocks of questionable Miocene age. Thus extrusion of the Espinaso volcanics may span Oligocene and early Miocene time.

Rapid lateral facies changes and a lack of fossils make exact correlation of the Espinaso volcanics difficult. The Picuris tuff described by Cabot (1938, p. 91) near Placita and Badito may be the correlative unit along the western flank of the Sangre de Cristo Range north of Santa Fe. Stearns (1953-b, p. 430-432) suggests that the volcanic conglomerate and flows in Arroyo Hondo, 4 miles south of Santa Fe, may be the correlative unit in that area. Elsewhere this volcanic unit may grade laterally into clastic sediments of the Santa Fe group as the amount of volcanic material available for deposition diminished with increased distance from source areas.

CIENEGUILLA LIMBURGITE AND ASSOCIATED INTRUSIVE ROCKS

The Cieneguilla limburgite was named by Stearns (1953-b, p. 445) for the settlement of Cieneguilla, 2 miles northwest of Cienega, near which this distinctive mappable sequence of limburgite flows, tuff, and tuff-breccia is best exposed. Prior to Cieneguilla deposition, erosion had partly stripped Espinaso pyroclastic rocks from the large stocklike monzonite porphyry masses at Cerro Seguro and Las Tetillitas. Limburgite volcanic rocks that unconformably overlie the Espinaso volcanics are conformably overlain by strata of the Abiquiu(?) formation. Associated with these extrusive rocks are many small limburgite dikes.

Limburgite flows interbedded with tuffs and tuff-breccias are exposed east of Cerro Seguro, north of Cerro Seguro in the canyon of the Santa Fe River, and near the mouth of the canyon. Limburgite flows form the peak of Cerro de la Cruz and project through Quaternary basalt flows a few hundred feet east of Las Tetillitas. On the north side of Cerro Seguro the Cieneguilla limburgite overlapped and may have covered the augite-biotite monzonite porphyry stock, which had been exhumed by post-Espinaso erosion.

In the canyon just north of Cerro Seguro, Brewster Baldwin (written communication) has measured a thickness of 730 feet of limburgite flows, tuffs, and tuff-breccias. About 4½ miles southwest of Cerro Seguro, in the canyon of the Santa Fe River, the Cieneguilla limburgite has thinned to 200 feet in thickness. In this area a basal flow of limburgite rests conformably on volcanic conglomerate of the Espinaso volcanics. This dark-purple, amygdaloidal flow is 25 feet thick. It is overlain by 100 feet of pink and tan lithic-crystal tuff that contains pieces of pumice and scoria and fragments and bombs of limburgite. A bed of green bentonitic clay containing a few calcareous concretions and lenses of pink limestone occurs above the tuff. This clay is overlain by the uppermost limburgite flow, which is 15 feet thick and is lithologically similar to the basal flow. In thinsection both flows appear similar to a limburgite dike that will be described in detail later.

Limburgite intrudes rocks as young as the Espinaso volcanics. Most of the intrusive limburgite was emplaced in north-trending dikes that occur throughout the Cerrillos area (pl. 1). The thickness of the dikes ranges from 1 to 6 feet. Along the strike dikes may terminate abruptly and then reappear at some distance along the same strike or one parallel to it. The thicker dikes commonly have a 6-inch to 1-foot chilled amygdaloidal zone along the contact. These zones are more resistant to weathering than the more coarsely crystalline dike centers. In hand specimen the dike rock is aphanitic, black, and weathers brown. In thin-section the rock appears to be holocrystalline and has a porphyritic texture. The estimated composition of the rock is:

	Percent
Labradorite, microcrystalline, interstitial laths and grains	10
Augite, pale-pink euhedral phenocrysts, 0.1-0.5 mm long and as microcrysts inthe groundmass	50
Olivine, light-green euhedral and subhedral plrenocrysts, 0.5-2 min in diameter	30
Magnetite, blebs 0.05-0.1 mm in diameter, in the groundmass	10
Total	100

The labradorite content of the rock as observed in a number of thin-sections ranges from 2 to 25 percent. Where this content is high the rock is an olivine basalt. A chemical analysis (Stearns, 1953-b, p. 450) of limburgite from Cerro de la Cruz is as follows:

Constituents	Percent of Total
SiO_2	40.18
TiO_2	2.66
$Al_2 0_2$	11.70
$Fe_2 0_3$	4.26
FeO	6.68

MnO	0.08
MgO	14.30
CaO	13.28
Na_2O	3.48
K_2O	0.73
H_20 +	—
H_20 -	1.66
P_20_5	0.68
SO_8	0.04
Cr_20_3	0.07
Total	99.80

Two small pluglike bodies of limburgite were observed just east of the Cerro Seguro stock. Stearns (1953-b, p. 446-447) considered the isolated exposure of limburgite on the top of Cerro Seguro to be a nearly circular plug that penetrated the older stock.

The small number of exposures of Cieneguilla limburgite makes it difficult to locate with certainty the vent or vents from which these volcanic rocks issued. However, the number of flows and total thickness of the unit increase from about 200 feet near the mouth of the canyon of the Santa Fe River to 730 feet just north of Cerro Seguro. The greater thickness of the limburgite rocks in the vicinity of Cerro Seguro indicates that this area was probably nearer the source. Stearns (1953-b, p. 446-447) has suggested that the limburgite plug on Cerro Seguro may have been a vent.

Near the mouth of the canyon of the Santa Fe River the limburgite pyroclastic rocks are well bedded and contain well-sorted material in which limestone nodules and lenses are present. This bedding and sorting suggest water transport and lacustrine deposition of the material. Nearer the source much of the rock was probably deposited from mud flow and air fall.

No fossil evidence for an age determination was found. However, the gradational relationship upward of limburgite volcanic rocks with the overlying Miocene(?) Abiquiu(?) formation may indicate that the Cieneguilla limburgite was deposited in early Miocene time.

SANTA FE GROUP

Hayden (1869, p. 167-170) applied the name Santa Fe marls to a "group of sands and marls which seem to occupy the greater part of the valley of the Rio Grande above and below Santa Fe." With a few refinements, Hayden's very loose definition of the Santa Fe unit was used until recently. In conjunction with geologic mapping near the city of Santa Fe, members of the staff of the New Mexico Bureau of Mines and Mineral Resources (Brewster Baldwin, written communication) have subdivided strata originally placed in the Santa Fe formation into three map units. These units comprise the Santa Fe group and are, from oldest to youngest, the Bishops Lodge member of the Tesuque formation, the

Tesuque formation, and the Ancha formation. This terminology has been modified in the Cerrillos area, where only strata similar to the basal and upper units of the Santa Fe group were found. Tuffaceous strata similar to the Bishops Lodge member are placed in the Abiquiu(?) formation. The name, Ancha formation, is used in both areas.

Abiquiu(?) Formation

The Abiquiu(?) is chiefly composed of tuffaceous sandstone and clay with lesser amounts of limestone. The maximum thickness of this formation exposed in the Cerrillos area is about 800 feet. The uppermost beds have been truncated by the Pleistocene(?) Ortiz pediment or covered by landslides and alluvium. The base of the formation was placed at the top of the uppermost flow of the Cieneguilla limburgite.

The only outcrops of this formation in the mapped area occur at and to the south of the mouth of the canyon of the Santa Fe River. In the canyon tilted beds of clay and tuff are truncated by the Ortiz pediment. A 30-foot bed of green clay containing yellow limestone nodules and a few latite pebbles rests conformably on the uppermost flow of the Cieneguilla limburgite. The next 30 feet is composed of pink and green lithic tuff. Above this tuff the section is largely covered by landslide debris.

Stearns (1953-a, p. 470) has described an incomplete section of this formation in an area extending southward from La Bajada. The lowest bed is an impure limestone 15 feet thick. This bed is overlain by about 125 feet of interbedded limestone and siltstone. A unit of red and gray clay and pebbly silt occurs next. Above a 100- to 200-foot covered zone the upper 625 feet is chiefly thin-bedded gray-white sand containing varying amounts of white tuff and pumice.

The presence of bedded limestone and chert in the lower part of the section and the high degree of sorting of the tuffaceous sands indicates that the lacustrine depositional environment of Cieneguilla time continued during the deposition of Abiquiu(?) sediments. The sand, clay, and volcanic pebbles may have been derived from erosion of uplifted strata adjacent to the numerous stocks and plugs emplaced during Espinaso volcanism. Tuff was derived either from reworking of Espinaso volcanics or from contemporaneous volcanism.

The Abiquiu(?) formation has been tentatively correlated with the Abiquiu tuff 50 miles north of the Cerrillos area (V. C. Kelley, oral communication, 1950; Stearns, 1953-a, p. 469). Stearns (1953-a, p. 472) has given an inferred age of early or middle Miocene for his Abiquiu(?) formation.

Downfaulting of the Rio Grande depression occurred in late Pliocene(?) time. Subsequent (pre-Ancha formation) erosion cut a graded surface that sloped gently upward from the ancient Rio Grande to all the existent highland areas. Bryan (1938, p. 218) correlated this surface with the Ortiz pediment south of Galisteo Creek and therefore the name Ortiz pediment is used in this report. Upon this surface sand and gravel of the Ancha formation (Santa Fe group) accumulated. Along the western side of the area these deposits were later blanketed by flows of Cuerbio basalt.

Renewed downfaulting of the Rio Grande depression was followed by dissection of the elevated block and the deposition of Recent stream channel deposits.

Ancha Formation

Beds of clastic and reworked pyroclastic material of the Ancha formation overlie the Ortiz pediment and underlie the Cuerbio basalt. These strata were previously mapped as the Santa Fe formation by Johnson (1903, p. 456) and Tuerto gravel by Stearns (1953-a, p. 476).

Except where removed by Recent erosion, flat-lying strata of this formation rest on a graded surface, which was cut into everything except the core of large intrusives and a few flows of the Cieneguilla limburgite.

Areal location with respect to source areas and drainage apparently controlled the type of material deposited on this pediment. On the eastern side of the Cerrillos, 50 feet of white water-laid tuff containing numerous gravel lenses rests on the pediment. About two-thirds of this gravel is composed of schist and granite pebbles and about one-third is latite pebbles. Above the tuff is a 25-foot layer of well-sorted, very fine-grained brown eolian sand. This is overlain by a 5-foot bed of gravel containing schist and granite pebbles.

In contrast to this eastern section is a section observed beneath the basalt a similar distance west of the Cerrillos. Here the lower 50 feet is composed of poorly sorted massive-bedded cobbles, boulders, and pebbles of lathe with a tuffaceous matrix. This is overlain by 15 feet of interbedded tuff and latite-bearing gravel.

The presence of schist and granite pebbles interbedded with fine-grained elastics suggests that low-gradient streams flowed westward from the Sangre de Cristo Range and deposited their load on the broad flood plains. The load consisted of metamorphic and igneous rocks from the Sangre de Cristo Range and also latite and tuff derived by erosion from Espinaso volcanics. The westward drainage pattern is further borne out by the accumulation of coarse latite detritus on the western side of the Cerrillos — the lee side with respect to major drainage.

Both the cutting of such an extensive pediment and the later covering of this surface with a thick veneer of clastic rocks may have required a larger volume of water than now flows down the Rio Grande and its tributaries. Such a volume of water could have been supplied by Pleistocene glaciation in the Sangre de Cristo Range and other mountains of Colorado and New Mexico.

A skull and tusk of a mammoth identified by Dr. E. H. Colbert of the American Museum of Natural History (D. F. Toomey, written communication) as *Archidiskodon imperator* was observed in gravels resting on the pediment surface approximately 1 mile southwest of Galisteo. In his monograph on Proboscidea, Osborn (1942, p. 998-1015) states that the age of this form ranges from Pliocene to late Pleistocene in southwestern United States. Inference and fossil evidence both indicate an early Pleistocene(?) age for this formation.

CUERBIO BASALT

These basalt flows were named Cuerbio by Bryan in an unpublished manuscript. Stearns (1943, fig. 2; 1953-a, pl. 1) later used this name in his maps of the area. For this report, basalt flows that are interbedded with and overlie the upper part of the Ancha formation, together with an associated cinder cone, have been placed in this formation.

Flows of Cuerbio basalt are restricted to the northwestern quarter of the mapped area (pl. 1). Here the resistant lava cap has protected the pediment surface from erosion except along a few deep canyons.

Two distinct flows of Cuerbio basalt were mapped. Where observed, the flows each average about 20 feet in thickness and exhibit columnar jointing. A zone of pipe vesicles occurs at the base of each flow. Flow tops are highly vesicular and scoriaceous. The center zone of each flow is dense, dark-gray or black, and contains few vesicles.

Thinsections show that the two flows are similar in texture and composition. The rock is a holocrystalline, porphyritic olivine basalt. Estimated mineral percentages are:

	Percent
Labradorite, flow-oriented phenocrysts, 0.05-3 mm long	60
Olivine, light-green euhedral and subhedral phenocrysts, 0.5-1 mm in diameter. Rims of reddish-brown hematite on olivine are common	20
Augite, yellow-green microcrystalline granules in the groundmass	15
Magnetite(?), as microscopic blebs in groundmass	5
Total	100

The surface of the low cinder cone north of U. S. Highway 85 has been subjected to erosion since deposition. The nature and structure of this pyroclastic cone can be observed in the cinder quarry on its west side. Most of the material consists of angular fragments of scoria one-fourth to one-half inch in diameter. A few large bombs and blocks are present. In this pit and elsewhere, beds of scoria dip about 30 degrees away from the center of the cone.

These flows issued from the cinder cone and from the crater area just off the northern edge of the mapped area. The surface upon which the lava was erupted sloped gently westward. This slope accounts for the greater area underlain by flow on the west side of the cinder cone. Whereas the first and most extensive flows from both centers of eruption may have joined to form a continuous sheet, the second flows were in probable contact only in a small area along their respective northeastern and southeastern edges. The second lava flow issued from the eastern side of the cinder cone. It flowed northward and southward around the base of the cone and then spread down the westward sloping top of the first flow.

Thus far no exact evidence for dating these flows has been discovered. The flows have been tentatively assigned to the Pleistocene epoch by Stearns (1942) and Brewster Baldwin (written communication). A small amount of gravel veneers the uppermost flow. This may be an indication that the flows were covered by gravel of the Ancha formation and later exhumed.

RECENT ALLUVIUM

This unit consists of talus deposits and post-Cuerbio stream-channel deposits. This unit generally was not mapped except in the western part of the area.

Talus has accumulated on the sides of most of the exposed intrusive masses. It generally consists of blocks of monzonite or latite similar to adjacent sources.

Stream erosion following Cuerbio basalt eruption and downfaulting of the Rio Grande depression channeled the old pediment surface to below present base level. These channels were then partly filled with sand and gravel from local or upstream sources. This filling is being removed by present stream erosion.

Structure

REGIONAL SETTING

The Cerrillos area is part of the La Bajada constriction, a positive element in the downfaulted Rio Grande depression (Kelley, 1952). The Rio Grande depression lies near the eastern border of the Basin and Range and Colorado Plateau physiographic provinces.

Rock exposures of Paleozoic and Precambrian age in the adjacent Sangre de Cristo, Sandia, and Jemez Mountains have yielded a history of structural events during those eras. Perhaps the most important of these events was a late Madera (Pennsylvanian) deformation, during which linear positive masses and flanking basins formed (Read and Wood, 1947, p. 225-227). The effects of this and other ancient deformations can be extended to the Cerrillos area. In the Cerrillos area, however, the upper part of the Chinle formation is the oldest outcropping rock, so that only post-Chinle structures can be studied.

Post-Chinle crustal movements have formed several major structural features, the most noticeable of which are three northward trending uplifts, the Sangre de Cristo to the northeast, the Sandia to the south, and the Jemez to the west. Associated with these uplifts is a series of northward trending echelon grabens, which form the Rio Grande depression (Kelley, 1952, p. 93). The locations of various basin subdivisions of the depression and the uplifts are shown in Figure 4.

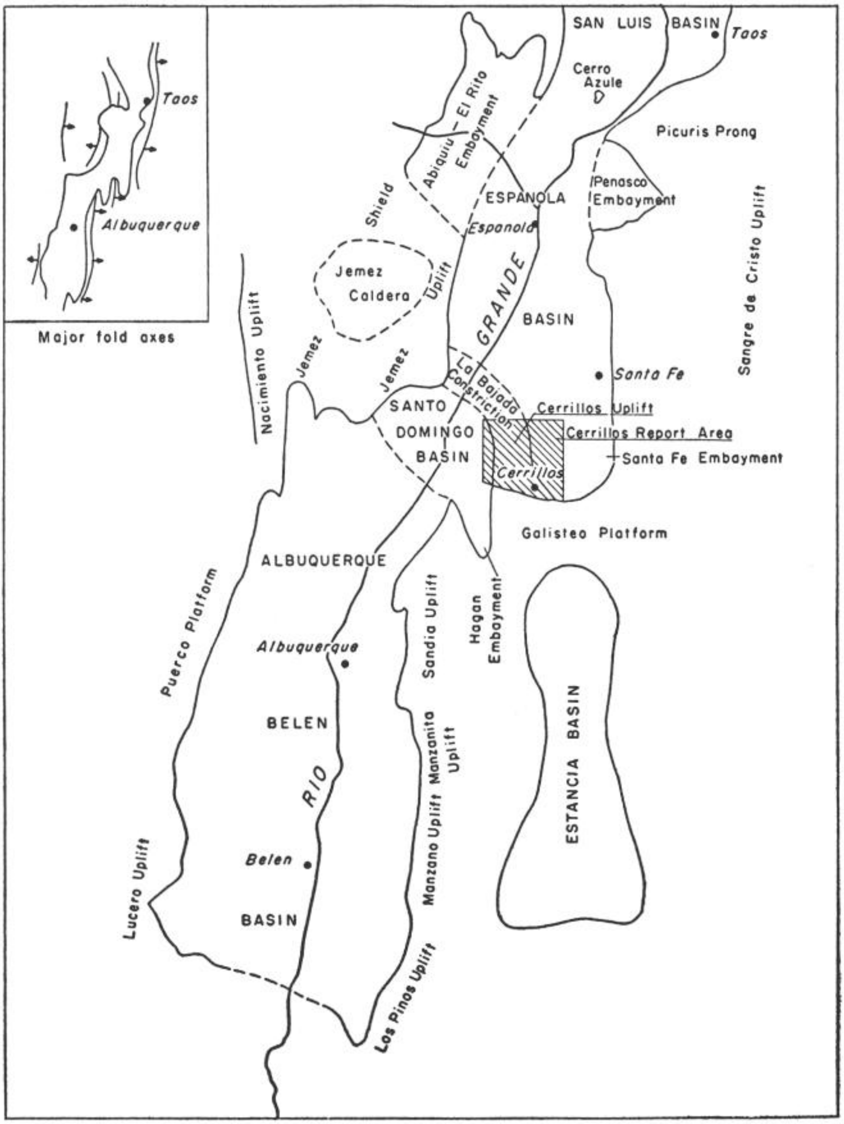
Somewhat more obscured by erosion and alluvium is a complex group of structural features caused by a series of middle-Tertiary monzonitic intrusions in the Cerrillos and, south-southwest of Cerrillos, in the Ortiz Mountains, San Pedro Mountain, and South Mountain.

Least obvious of all regional structures are those that resulted from slight but repeated emergence and submergence of the region with respect to sea level during Mesozoic time. Throughout most of this era the region lay within a large depositional basin. Differential rates of downwarping, resulting in varying rates of deposition within the basin, undoubtedly gave rise to minor folding in basin strata. This period of gentle downwarping was terminated along the eastern edge of the basin by uplift during Laramide orogeny.

LARAMIDE STRUCTURE

After deposition of Upper Cretaceous sediments in the basin, a gradual uplift commenced in the vicinity of the present Sangre de Cristo Range. Contemporaneous with uplift was the formation of an erosion surface extending outward from the highland.

In an isopach-lithofacies map of the San Juan Basin, Silver (1950, p. 113) shows Paleocene sediments overlapping eastward onto progres-



MAJOR TECTONIC FEATURES OF THE RIO GRANDE DEPRESSION, NORTHERN NEW MEXICO (after V. C. Kelley).

Figure 4

sively older Cretaceous units. The direction of maximum erosion was about due east. In the Cerrillos and adjacent areas the direction of maximum erosion was northeastward at a rate of 130 feet per mile. A maximum thickness of 2,100 feet of post-Mancos Upper Cretaceous strata has been preserved in the Hagan area, 14 miles southwest of Cerrillos. One mile southwest of Cerrillos this unit was eroded to a thickness of 760 feet. In the canyon of the Santa Fe River, in the northern part of the mapped area, the Galisteo formation of Eocene and Oligocene(?) age rests on the upper part of the Mancos shale.

Although the difference in attitude between Upper Cretaceous units and units of the overlying Eocene is so slight that it was not detected in the Cerrillos area, Stearns (1943, p. 315) observed channeling and gradual truncation of Upper Cretaceous units prior to the Galisteo deposition.

Throughout Eocene time the deposition of progressively younger strata overlapped the erosion surface in a sourceward direction. As the thickness and weight of deposited material increased, local downwarping occurred. The Cerrillos area lay in the northwest sector of the Eocene Galisteo basin, which is one of these downwarps. Evidence of this downwarping has been masked by major structural deformation during subsequent Oligocene igneous intrusions.

STRUCTURAL DEFORMATION BY OLIGOCENE MONZONITIC INTRUSIONS

A series of Oligocene intrusions of monzonitic composition caused a complex sequence of major folding and faulting of the host strata in the Cerrillos area. Early workers thought the hills were remnants of great dikes or remnants of old volcanoes. Johnson's work (1903, p. 463) in the area led him to propose a laccolithic structure for most of the Cerrillos igneous masses. As evidence he offered the following:

1. No fragments of eruptives found in associated strata.
2. Rock is not vesicular or fragmental but granitoid.
3. Strata dip away from hills at high angle.
4. Igneous bodies are definitely intrusive with apophyses.
5. Contact phenomena were noted with intruded sediments.
6. Intrusive sheets dip away from intrusive.

In commenting on a regional pattern of similar intrusive rocks, he stated (1903, p. 457):

> . . . it is interesting to note that the groups of laccolithic mountains of which the Cerrillos Hills form the northernmost member, are arranged along a nearly north-and-south line. The rocks composing them are of the same general character, as shown by the study of thin sections, while their mode of occurrence is similar. It seems not unlikely, then, that the Cerillos, Ortiz,

> San Pedro and South Mountains occur along one of the great north-and-south fractures, which fractures served to release the andesitic lava confined below. The fracture died out before reaching the surface, so that the rising molten lava spread laterally, and arched up the overlying beds, forming great laccolithic intrusions.

Lindgren (Lindgren et al., 1910, p. 165) also believed that the intrusive represented one or two laccoliths from which intrusive sheets projected into adjoining strata. He cited holocrystallinity of the rock as evidence for consolidation far beneath the surface. More recently, Stearns (1953-b, p. 415) has described most of the intrusive masses as stocks.

Field work for this report has revealed no evidence that the first monzonitic intrusions occurred along faults that reached the surface. The major bodies are stocks or plugs from which radiate tongue laccoliths, sills, and dikes. These radial intrusions were emplaced in greatest number and volume in the thick section of relatively incompetent Mancos shale.

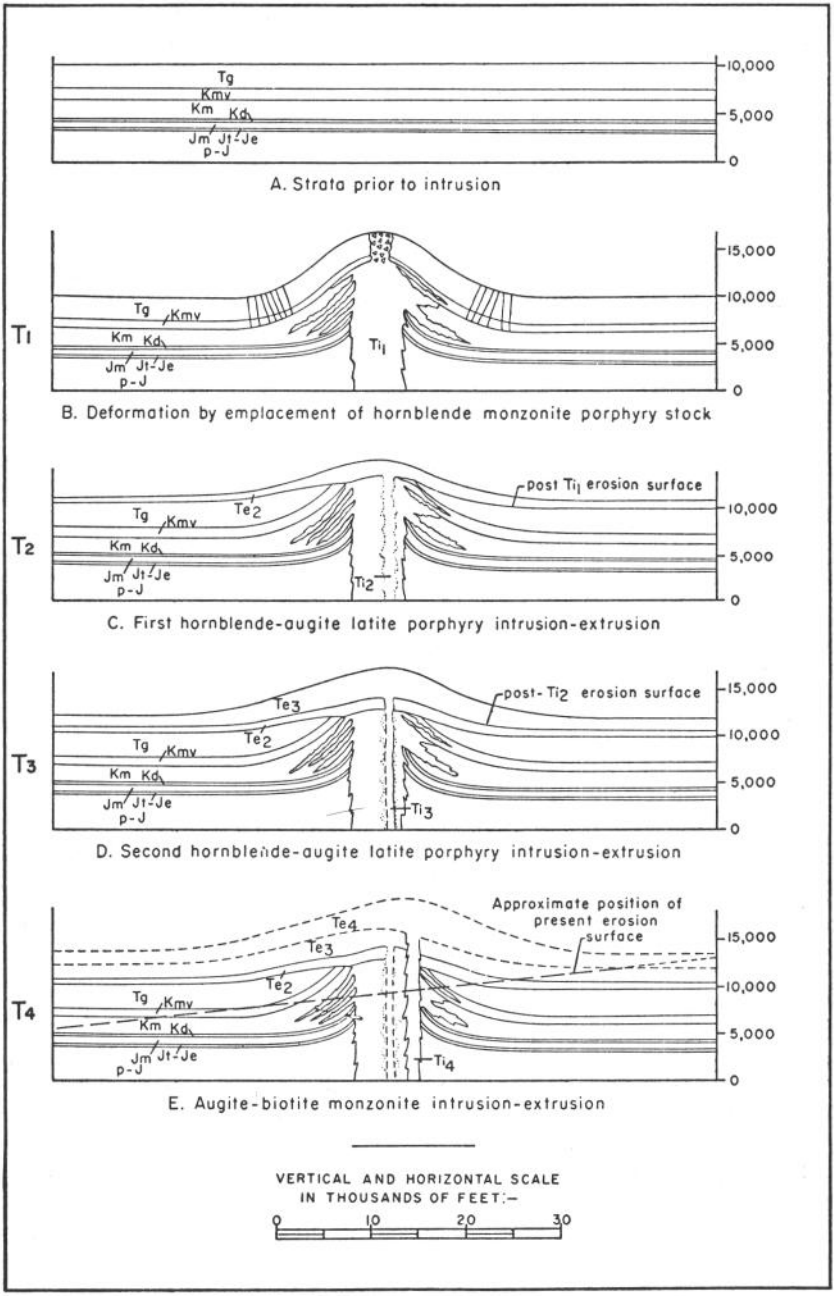
The Cerrillos intrusions in many respects are similar to the intrusions, in the Henry Mountains of southeastern Utah (Hunt et al., 1953, p. 90). Each of the Henry Mountains consists of a stock around which laccoliths or other intrusions are clustered. The stocks were the chief centers of intrusion, located in the center of the mountain domes, whereas the other intrusions, which are distributed on the flanks and across the top of the domes, appear to have been injected radially from the stocks and form, for the most part, bodies that are concordant with bedding of the sedimentary rocks. Laccoliths (Hunt et al., 1953, p. 90, 143) are tongue shaped in plan and were emplaced in greatest number and volume in incompetent shale of the upper part of the Morrison and Mancos formations.

Four major periods of monzonitic intrusion occurred in the Cerrillos. Each period was separated from the other by an interval of time. Intrusions emplaced during all four periods caused some deformation of the host strata (fig. 5).

IGNEOUS PERIOD T_1

A forceful intrusion of hornblende monzonite porphyry into a nearly flat-lying sequence of sedimentary rocks marking the beginning of Oligocene igneous activity in the Cerrillos. Eroded remnants of this intrusion occupy 9 square miles just north of Cerrillos. Smaller bodies crop out west and south of Santa Rosa Mountain and at Turquoise Hill (pl. 1).

A probable low temperature for this magma at the time of emplacement is indicated by a baking of host rock, which seldom extended more than 2 or 3 feet beyond the igneous contact. The magma must have been rather viscous and therefore of low stoping ability. It could be em-



DIAGRAMS OF EMPLACEMENT OF CERRILLOS INTRUSIONS AND EXTRUSIONS, IGNEOUS PERIODS T_1, T_2, T_3, AND T_4. Data modified from structure section D-D′, Plate 1.

Figure 5

played only by forceful deformation of invaded rock (fig. 5B). Where stoping is negligible, the location of the hinge line and the attitude of beds pierced by an intrusive body ought to give an indication of diameter of the intrusive body itself. The larger the diameter, the farther the hinge line ought to lie from the intrusive body, or the steeper the beds ought to tilt adjacent to the intrusive body.

The large T_1 and the smaller $\mathbf{T_4}$ intrusive bodies 1½ miles northeast of Cerrillos are exposed for about 14,000 feet along cross-section D-D' (pl. 1), but they are shown with a combined width of 8,000 feet at a depth of half a mile. The greater width at the surface may represent a mushrooming of the stock in the Mancos shale. The tilt of Mesaverde and Galisteo units adjacent to this intrusive indicates that maximum uplift over the center of the stock was about 7,000 feet (fig. 5B).

There were apparently three major overlapping phases in the emplacement process. These were:

1. Intrusion of plastic magma as a stock or plug, about 6,000 feet in diameter, which pierced, upturned, and fractured host strata until it reached the caprock formed by massive sandstone beds of the Mesaverde and Galisteo formations. The magma may have broken through these formations and breached the surface.
2. Plugging of conduits (if any) through the arched caprock, by solidification or by blocks of older sedimentary rocks torn loose at depth and pushed upward by the plastic magma (see top of fig. 5B).
3. Continued magmatic pressure, causing the injection outward from the stock or plug of dikes, tongue laccoliths, and sills of hornblende monzonite porphyry.

The structural effect of the first phase of emplacement was the creation of a symmetrical domal uplift. Maximum uplift during this phase was about 5,000 feet over the crest of the dome. The dip of beds away from the intrusive mass diminished from about 50 degrees near the contact to zero about 8,000 feet from the contact.

During the first phase a system of radial faults was formed in the pierced strata by the pressure of rising magma against the walls of the conduit. Away from the intrusive masses the displacement of beds along these faults diminished rapidly, and the Mancos shale absorbed most of the movement. Near the intrusions these faults were filled by the magma. Their presence can be inferred by an offset of beds on opposite sides of dikes, many of which have very irregular shapes. The exposure of Dakota and Morrison units surrounded by intrusive rock 1 mile northeast of Waldo is thought to lie between two of these inferred radial faults. This block moved an apparent horizontal distance of about 1,500 feet in a southwesterly direction away from the stock.

A system of roughly concentric fractures formed in sandstone and other units incapable of bending under the first phase of deformation (fig. 5B). Where observable in the massive basal sandstone of the Mesaverde formation 1 mile southwest of Waldo, displacement of beds is small. The maximum apparent horizontal displacement that was measured is 500 feet.

In response to the doming, the Mesaverde-Galisteo caprock may have yielded by tension fractures and faults. These features could have served as conduits for magmatic extrusion. However, evidence for existence of these features has been destroyed by erosion of the caprock. Furthermore, apparent absence of hornblende monzonite porphyry at the base of the volcanic section may be an indication that this magma did not reach the surface.

Although the thick sequence of Mancos shale formed the most favorable zone for injection of third-phase dikes, tongue laccoliths, and sills, hornblende monzonite magma was forced also into shale zones of the Mesaverde and basal Galisteo formations along the eastern edge of the hills. Apparently magma was pushed outward from the stock or plug along the radial faults formed during the first phase of intrusion. When barriers were encountered, further movement of magma along these faults was halted. Tongue laccoliths and sills then formed in the upturned sediments.

Although minor folds were developed in the host rock during the injection of these sills and laccoliths, the major structural effect of their emplacement resulted from a thickening of the Upper Cretaceous section by about 2,000 feet near the stock or plug. This thickening elevated the crest of the dome from 5,000 to 7,000 feet and extended the radius of outward tilt in post-Dakota strata from 8,000 to 11,000 feet away from the contact.

A similar sequence of structural and intrusive events undoubtedly occurred during the emplacement of the smaller bodies of hornblende monzonite porphyry south and west of Santa Rosa Mountain, at a small hill a quarter of a mile northwest of Marshall Bonanza shaft, and at Turquoise Hill. In these areas alluvial cover and deformation by later intrusion have masked the evidence needed for reconstruction of the structure associated with this period of intrusion. In cross-section the hornblende monzonite porphyry bodies are shown to be stocks (pl. 1). It is possible that these intrusive masses are sills or laccoliths in the lower part of the Mancos shale or upper part of the Morrison formation, which were pierced and uplifted by later intrusions.

IGNEOUS PERIODS T_2 AND T_3

During two periods of igneous activity, intrusions of hornblendeaugite monzonite porphyry were forced upward through the hornblende monzonite stock and became extrusive. Although T_2 and T_3 intrusive rocks are not mapped separately from T_1 intrusive rocks, intrusive relationships were noted at several places in the southeastern part of the hills.

Deformation associated with the T_2 and T_3 intrusive periods was slight. Undoubtedly some lateral pushing of the conduit walls occurred as the plugs and dikes were emplaced. Because of the small size of these bodies, and because of their location, mainly within the T_1 intrusive mass, any additional uplift or folding caused by them is inseparable from the earlier uplift.

IGNEOUS PERIOD T_4

A series of augite-biotite monzonite stocks or plugs, sills, tongue laccoliths, and dikes having similar mineral constituents in varying proportions were emplaced during the T4 igneous period. Evidence that this magma had a high temperature and contained many volatile substances was observed in the baking, silicification, and hydrothermal alteration that extends outward several hundred feet into host sediments and volcanic masses. It is probable, then, that emplacement of intrusive bodies of this magma occurred with some stoping of the host rock and therefore with less structural deformation than was associated with the T_1 intrusion. The main intrusions occurred either in or adjacent to older stocks.

The largest of the T_4 intrusions forms the entire northern end of the Cerrillos, an area of about 1½ square miles. Along its western edge this intrusive mass is in contact with hornblende monzonite porphyry and with sandstone beds of the Dakota and Morrison formations, which dip steeply to the west. On the south the lower part of the Mancos shale and volcanic(?) strata form the host rock. Along the east side, volcanic rocks of the earlier periods, as well as T_4 volcanic rocks, dip outward from the augite-biotite monzonite body at relatively low angles. One concealed radial fault along the northern side of this body (pl. 1, S1/2 sec. 18, T. 15 N., R. 8 E.) appears to have been caused by lateral pressure during intrusion. This fault has a horizontal displacement of 2,000 feet and a northerly trend, is vertical, and was immediately filled with magma. A system of radial dikes of augite-biotite monzonite indicates additional fracturing during intrusion. Offset of beds by these fractures was slight.

Lineation of elongate minerals in many of these dikes plunges 30 degrees toward the intrusive. The distal ends of augite-biotite monzonite dikes half a mile west of Waldo and a quarter of a mile east of Cerrillos are at right angles to their major trend through the Mancos shale. In both places the changed trend of the dikes is parallel to the strike of the adjacent massive basal sandstone of the Mesaverde formation, which formed a barrier and caused their deflection.

The stocklike intrusive mass at Turquoise Hill is also in association with hornblende monzonite porphyry and upper strata of the Morrison formation, Dakota sandstone, and lower part of Mancos shale. Here the outward dip of the strata appears to be associated more closely with the earlier hornblende monzonite intrusive body than with the augitebiotite monzonite body.

On the eastern edge of the hills at Rocky Butte, and just north of Cienega, at Cerro Seguro, a porphyritic facies of this magma intruded and deformed strata of the Galisteo formation and volcanic rocks associated with earlier periods of intrusion. These intrusive bodies were probably much more viscous than the larger monzonite bodies. Their emplacement, therefore, caused greater deformation of the host rock. The fault contact along the southwest side of the Cerro Seguro mass may have formed during forceful intrusion.

The intrusion in the canyon of the Santa Fe River tilted beds of the Mancos shale outward at an angle of about 30 degrees. The intrusions at Mt. McKenzie, Grand Central Mountain, and Franklin Hill invaded a host rock of hornblende monzonite porphyry and older volcanic rock. Hydrothermal alteration has made it difficult to decipher the structure without detailed petrographic work. It is also difficult to distinguish between hornblende monzonite porphyry that may have been brecciated by this intrusion and the flow breccias associated with earlier periods of intrusion. The structural effects of the other numerous intrusions of this magma are not known, either because evidence has been obscured by gravel cover of the Ancha formation, or because of a lack of marker units in the early volcanic strata.

POSTINTRUSIVE FRACTURING

At some time after the solidification of the youngest monzonitic intrusions a complex system of fracturing developed. On aerial photographs it was noted that piñon and juniper trees often grew along these fractures. A result of a plot of "tree lines" in the center of the area is shown on Plate 2.

Although it is difficult to assign a definite cause to their formation, these fractures may represent an adjustment of intrusive and host rock to:

1. Shrinkage due to contraction of rock on cooling.
2. Tension in the rock from a relaxation of magmatic pressure from below.
3. Compression of the rock by late upthrust of liquid beneath solidified intrusive.

During adjustment, a network of branched large fractures developed. Terminating against these larger fractures are many smaller fractures, which resulted from tension or compression on blocks of rock between the larger fractures.

Fractures of this system have trends in many directions. There is, however, a dominant north-northwest fracture orientation, which roughly parallels the axis of elongation of the combined intrusive masses in the center of the hills. The dip of most fractures is greater than 60 degrees. No dominant direction of dip is apparent.

Fracturing is most prominent in the intrusive masses; though fractures are numerous in the host rock adjacent to intrusions, the number decreases away from them. Contacts are offset along very few of these fractures, indicating that movement was slight. Brecciated wall rock along some of the larger of these fractures served as channels for the transportation of ore-bearing solutions and as sites for deposition of ore and gangue minerals. A few of these fractures formed planes of weakness along which dikes associated with the Cieneguilla limburgite were intruded.

CIENEGUILLA AND ABIQUIU(?) STRUCTURE

Deformation during Cieneguilla and Abiquiu(?) time was probably slight. Within the region, 1,000-3,000 feet of Cieneguilla limburgite and Abiquiu(?) formation was deposited (Stearns, 1953-a, fig. 8, 9). Basins may have warped down under the load of accumulating sediments. Such deformation could not be detected in the lower part of the strata, which is all that crops out in the Cerrillos area. The emplacement of limburgite dikes during Cieneguilla time deformed the intruded rock. Because these dikes are small, the amount of deformation was slight.

PRE-ANCHA DEFORMATION

Major structural deformation occurred during or at the end of Pliocene(?) time. Of this deformation Johnson (1903, p. 456) has written:

> The movement which produced this uniform eastward dip was probably the same which resulted in the great monoclinal uplift of the Sandia Mountains some thirty miles to the southwest. [Except for local uplift disturbances, beds dip eastward in this general area.]

For the deformation producing this tilt, Johnson proposed the name Sandia Uplift. He associated with the uplift a series of northward trending fractures, which he believed to be the probable reason for the series of Recent volcanoes along a north-south line. These volcanoes evidently include the cone west of the Cerrillos and those in the Cerros del Rio about 10 miles northwest of Cienega. Bryan (1938, p. 213) believed the uplift occurred after deposition of the Santa Fe formation. The absence of Abiquiu(?) formation at the base of Santa Fe strata on the north side of the Sandia Mountains has led Stearns (1953-a, p. 482-491) to assign a pre-Abiquiu(?) date to this period of uplift and folding.

In the Cerrillos area Abiquiu(?) strata rest conformably on the Cieneguilla limburgite, and both units seem to have been involved in the same deformation.

Major faulting attributed to this period of deformation occurred along the western edge of the area. The Rosario fault (Stearns, 1953-a, pl. 1, p. 481) has an irregular northerly to northeasterly trend and has thrown the Galisteo formation on the west down against the Chinle formation on the east (pl. 1, sec. C-C'). This fault dips 50 degrees to the west and has an apparent vertical displacement of about 4,500 feet. The trace of the fault plane on the surface swings from a northerly direction, along its southern extremity, to N. 30°-40° E., in the vicinity of La Bajada Hill (pl. 1). Although some of this change of direction may be due to an increase in elevation of the fault trace, most of the change is caused by a bend in the fault plane. A series of roughly parallel faults west of the major break represents readjustment within the hanging-wall block during the major adjustment (pl. 1, sec. A-A', B-B').

Minor drag folding occurred in sediments near the fault. Major folding is represented by eastward tilting of the footwall block to about 12 degrees. Prior to this tilt, beds along the western edge of the area were relatively undeformed, and their present attitudes indicate the degree of tilt. Farther east, the effects of this tilt are somewhat masked by deformation associated with Oligocene intrusions. It will be noted that progressively younger beds are cut by the intrusive masses to the east. If, in cross-section, one removes the 12-degree tilt and then draws a horizontal erosion surface across the area, it becomes apparent that the sedimentary rocks and volcanic rocks were deformed symmetrically by the monzonitic intrusions. The present asymmetry, with intrusions of monzonite into Mancos, Dakota, and Morrison strata on the west side of the hills and into Mesaverde and Galisteo strata on the east, was the result of eastward regional tilting and truncation during Pleistocene(?) pedimentation.

This period of block faulting and tilting was followed by the cutting of an extensive pediment surface outward from the Sangre de Cristo Range. This surface extended from the front of the Sangre de Cristo Range to the ancient Rio Grande, lapping against the more resistant intrusive cores in the Cerrillos area. Bryan (1938, p. 215) correlated this surface with the Ortiz pediment south of Galisteo Creek.

POST-CUERBIO BASALT DEFORMATION

The period of pedimentation was brought to a close by a recurrence of normal faulting along the boundaries of the Rio Grande depression on the western edge of the Cerrillos area. The northward trending fault along which this movement occurred has been covered by Recent stream gravel in the Cerrillos area. Evidence of movement along this fault has been reported in White Rock Canyon a few miles to the north. There the fault strikes N. 20° W. The west side of the fault was dropped 300 feet (Emmanuel, 1950). Kelley (1952, p. 95) believes that the surface at the base of La Bajada escarpment is the Ortiz surface, which has been dropped along a northward trending concealed fault near La Bajada and then buried to some extent by material washed in from above the fault and by material brought in along Galisteo Creek. Tilted basalt flows in this downthrown block 2 miles northwest of La Bajada appear in thinsection to be identical with the basalt of flows capping the Ortiz pediment on the east side of the fault scarp.

As a result of this faulting, the upthrown side east of La Bajada scarp has been dissected deeply. Following dissection, stream channels were filled slightly with sand and gravel. These channel deposits recently have been removed or dissected by rejuvenated stream action.

Mineral Deposits

HISTORY AND PRODUCTION

The Cerrillos district has produced zinc, lead, silver, gold, and copper from one group of deposits, and turquoise from another group. According to Northrop (1944), numerous prehistoric workings, and stone hammers and other primitive implements have been found in the district. In a village in Chaco Canyon, about 85 miles west-northwest of the Cerrillos area, archaeologists found turquoise ornaments that date back to the period A.D. 950-1150; the Cerrillos area was undoubtedly the chief source of this turquoise. Metal-bearing ores in the Cerrillos area were observed in situ by members of the Rodriquez-Chamuscado expedition of 1581. In 1583 and again in 1590-1591, ore deposits were found and assays made of the ore in the Cerrillos-Ortiz Mountains region.

The age and great size of the turquoise workings aroused the wonder of early American visitors to the district. According to Pogue (1915, p. 52), Mt. Chalchihuitl in the Cerrillos district appears to be "the site of the most extensive prehistoric mining operations known on the American continent." Johnson (1904, p. 87) states that the Turquoise Hill deposits, also in the Cerrillos district, were worked by the Indians perhaps as early as those on Mt. Chalchihuitl.

Prospecting and mining for turquoise ceased almost entirely for a century, when the revolt of the Pueblo Indians in 1680 drove the Spaniards out. Some writers have held that the revolt was caused at least in part by the enslavement of the Indians in the mines. Johnson (1904, p. 88) relates that part of the turquoise workings in Chalchihuitl Hill caved in in 1680, crushing a number of Indian miners, and that this accident has been considered by some as the immediate cause of the uprising.

Evidence also exists that Mina del Tiro, in the Cerrillos district, is one of the most ancient metal mines in North America. Jones (1904, p. 30) states:

> Beside the ancient turquoise mines, there exists a metal mine which was worked for its silver and lead, and is almost as old as the *Chalchihuitl* workings; this is known as *Mina del Tierra*. In this mine exists the only real evidence of ancient lode mining in the southwest; it antedates the first work done in the Ortiz and Santa Rita mines by at least a century.

The excavations are thought to have been made by Indian slaves under the direction of the Jesuits prior to 1680 (Jones, 1904, p. 30).

After the period of Mexican rule from 1821 to 1850, zinc-lead-silver ores again were discovered in the district in 1879. A boom started, and more than a thousand locations were made within a short time (Northrop, 1944, p. 25). In the early 1880's Carbonateville (1 mile north of Cash Entry) and Bonanza City (a quarter of a mile southeast of Cerro de la Cruz) in the Cerrillos district were prosperous mining camps. During this period a mineral survey was made by Hayward (1880), who published a document stating the local mining laws and conditions and describing the mines in encouraging terms.

In his report on the geology of the Cerrillos Hills, Johnson (1904, p. 92) mentions prospecting and mining as being carried on every summer. His only reference to ore production is to earlier shipments from the neighborhood of the Cash Entry and Grand Central mines. Mention is made (Northrop, 1944, p. 319), however, of the workings of the American Turquoise Co. on Turquoise Hill, from which gems having a total value of at least $2,000,000 were extracted during the 1890's.

In 1902 a smelter was erected near Cerrillos, but it was unable to treat the complex ores successfully and closed in 1904. Some ore from the Cochiti district, about 20 miles northwest of Cerrillos, and the Ortiz district, about 7 miles south-southwest of Cerrillos, was processed during its operation. Lindgren (Lindgren et al., 1910, p. 166) mentions shipment of ore from the Tom Payne mine and states that silver-lead ore was mined in the district during the boom period, but that its total value to the time of his visit probably did not exceed a few hundred thousand dollars.

During the period 1905-1952 ore was produced intermittently from the Tom Payne, Evelyn, Grand Central, Cash Entry, Pennsylvania, and smaller mines. The available production figures are given in Table 2. The Tom Payne mine had a considerable production during 1915-1917, and a mill, which has since been dismantled, was built on the site of the old Cerrillos smelter. In 1945 the Pennsylvania mine was the only steady producer. Exploration by the Sierra Metals Co. was under way in the Black Hornet prospect, but this work reportedly was abandoned in 1946. Plans also had been formulated by the Moline Mining & Milling Co. for a continuation of work operations in the Franklin mine.

TURQUOISE DEPOSITS

All the Cerrillos district turquoise deposits lie in sericitized, slightly tourmalinized igneous rock. The principal deposits are on Mt. Chalchihuitl and Turquoise Hill, but many small workings and pits lie scattered in other areas of altered rock. The Blue Bell turquoise mine, southeast of the Cash Entry mine, was worked intermittently from 1900 to 1925 by Michael O'Neill, and high-quality gem material was produced.

Turquoise Hill is covered with patented mining claims, including the Blue Bell, Blue Gem, Morning Star, Gem, Sky Blue, Muniz, Castillian, and Elisa lode claims. The workings are known locally as the

TABLE 2. ANNUAL ORE AND METAL PRODUCTION OF THE CERRILLOS DISTRICT, 1909-1952

(Data from Minerals Year Books, U. S. Bureau of Mines)

		GROSS METAL IN ORE OR CONCENTRATE				
YEAR	ORE (TONS)	GOLD (OZ)	SILVER (OZ)	COPPER (LB)	LEAD (LB)	ZINC (LB)
1909	2,821	16.04	2,285	1,093	213,558	4,426
1910	4,617	19.57	3,300	5,150	262,023	74,759
1911	51	16.58	1,915	4,494	11,178	——
1912	752	.39	1,040	8,670	12,511	10,565
1913*						
1914	287	2.91	779	7,575	52,948	89,860
1915	700	6.14	426	1,766	50,638	14,556
1916	2,546	7.14	2,175	——	166,304	334,321
1917	3,118	1.11	142	2,579	17,779	512,628
1918	172	——	——	——	11,000	94,572
1919-1921*						
1922	40	1.00	——	——	8,800	19,840
1923-1925*						
1926	807	210.10	1,011	41,800	24,500	——
1927	1,644	303.70	1,120	71,771	8,635	——
1928	300	42.09	205	12,174	2,466	——
1929	87	5.60	34	3,552	——	——
1930-1932*						
1933	40	28.30	7	——	——	——
1934	68	31.93	89	700	5,000	——
1935	9	32.08	14	——	100	——
1936	110	82.20	13	370	——	——
1937*						
1938	32	16.80	20	300	——	——
1939	19	9.00	13	200	——	——
1940	13	18.00	1	100	——	——
1941	42	14.00	3	——	——	——
1942	65	1.00	201	300	11,800	14,000
1943	207	2.00	543	800	32,000	46,000
1944	447	3.00	599	1,200	37,800	57,000
1945	1,844	6.00	1,786	2,000	102,000	120,000
1946	2,166	17.00	1,952	1,800	140,000	79,000
1947*						
1948	1,133	9.00	126	2,000	58,000	38,000
1949	643	6.00	757	——	38,000	14,000
1950*						
1951	369	9.00	789	2,500	58,000	76,000
1952	334	3.00	842	2,000	54,000	72,000
Total	25,843	920.68	22,187	174,894	1,379,040	1,671,527

* No production.

Castillian or Tiffany mine. On the east end of the hill are two adits with stopes connecting to the surface, and a number of pits. On the west end of the hill are shafts, stopes, open pits, and a large number of prospect cuts. Apart from some desultory work in recent years, the Turquoise Hill mines have been idle for about 50 years. They are reported to have produced a higher proportion of high-grade gem material than any other deposit in the United States (Northrop, 1944, p. 320).

The turquoise deposits were visited only briefly in connection with the present work and, inasmuch as the mines have been idle for many years, little could be learned of the detailed occurrence of the gem mineral. Little turquoise is now visible in the workings. It is reported to occur as nodules in narrow fracture zones and as veinlets cutting the altered rock; specks of turquoise are plentiful in some of the dump material. Fresh pyrite occasionally was found enclosed in masses of turquoise. The gem was greenish blue or sky blue but commonly contained streaks of kaolin and limonite. A specimen from Mt. Chalchihuitl, deep green and resembling variscite, gives the same X-ray powder pattern as massive turquoise, although containing less copper.

For detailed descriptions of the occurrence and mineralogy of the turquoise, reference is made to Clarke and Diller (1887) and Johnson (1904, p. 192-203). A bibliography of articles dealing with New Mexico turquoise is given by Northrop (1944, p. 315-316).

ZINC-LEAD VEINS

GENERAL FEATURES

The only deposits being mined in the Cerrillos district in 1952 were narrow sulfide veins containing zinc, lead, and a little copper, silver, and gold. Small tonnages of oxidized copper and zinc ores were mined in earlier years. A few veins are composed almost entirely of quartz, but in most of the productive deposits gangue minerals are not abundant. Although some veins cut the Espinaso volcanics and Galisteo strata east of the Cerrillos, most, including all that have been productive, lie in the central augite-biotite monzonite porphyry and surrounding hornblende monzonite porphyry. A few are found in the immediately adjoining Mancos shale and in sedimentary inclusions surrounded by igneous rock.

The average grade of ore mined between 1905 and 1952 was low. Excluding oxidized copper ore mined at the Evelyn property, the average ore from the district yielded only about 5.0 percent zinc, 3.6 percent lead, and 0.1 percent copper, and 1.1 ounces of silver and 0.01 ounce of gold per ton. The ore from some mines, and small high-grade shipments from many mines, have been of considerably higher grade than the average.

MINERALOGY

In the accessible mines of the district, sphalerite, galena, chalcopyrite, and pyrite are the chief primary ore minerals. Silver occurs with galena, and gold appears to be associated largely with the chalcopyrite. Quartz, carbonates, and a little barite, opal, and chalcedony are the gangue minerals. Bournonite and stibnite have been reported (Northrop, 1944, p. 294).

Locally the galena is fine grained, but for the most part it is coarsely crystalline; the cubes range from a quarter of an inch to 3 inches on edge. At the Pennsylvania mine a few galena octahedrons have been reported. Sphalerite likewise is mainly coarse grained and is resin colored or less commonly coffee colored. Sphalerite locally contains innumerable microscopic blebs of chalcopyrite, and the intergrowth has a silvery-gray color. Chalcopyrite is also present in minor amounts as blebs and streaks in the lead and zinc sulfides. Pyrite, though not abundant, is widely distributed as small crystals forming minor stringers, disseminations, and coatings in the ore, and as disseminations in the sheared vein zones and in the adjoining altered wall rock.

Quartz is commonly the gangue in which the ore minerals are dispersed. White or gray medium- to fine-grained quartz forms layers in "crustified" sulfide ore, or it forms stringers containing disseminated sulfides. In sheeted ground, quartz forms parallel veinlets alternating with thin layers of altered rock. Tiny crystals of clear quartz line the small vugs, which are common in the ores. In the Black Hornet prospect, crystals of amethystine quartz were observed in a small solution cavity in the vein. Some quartz veinlets have coarse comb structure and include a narrow central ribbon of amethyst. Quartz also occurs as small plates pseudomorphous after another mineral, possibly lamellar calcite.

Red chalcedony is mixed with coarse white quartz in ore from the Franklin mine. Bluish-gray chalcedony and light-brown opal occur in minor quantities throughout the district as veinlets, vug linings, and local fillings. Ankerite and calcite are common gangue minerals, and siderite also may be present. Ankerite, much of which contains sulfides, is finely to coarsely granular and occurs as irregular patches and stringers in the veins. Calcite, some of which is lamellar, occurs as massive vein fillings, as stringers, and as drusy vug linings. Rhodochrosite is present in the Marshall Bonanza and Black Hornet mines. Blades of barite locally form boxworks in a matrix of quartz or carbonate.

Although detailed studies of paragenesis were not made, the general sequence of vein minerals appears to be as follows, in order of deposition: ankerite and quartz; pyrite; sphalerite; galena; chalcopyrite; pyrite; calcite, opal, quartz, and chalcedony.

WALL-ROCK ALTERATION

The igneous wall rocks, as well as the sheared rock of which the veins mainly are composed, have been slightly to highly altered by hydrothermal solutions for distances of 1 to 10 feet on either side of the veins. Sericite is the principal alteration mineral and gives the normally gray rocks a whitened, bleached appearance. Less commonly, and at greater distances from the veins, light-green chloritized rock is found. Pyrite, carbonates, and silicas are likewise present.

Plagioclase is partly converted to sericite and carbonate. Orthoclase is unaltered, but interstitial quartz may be replaced to a slight extent by sericite. Biotite is changed to muscovite. All the mafic minerals were obliterated; where alteration has been thorough, the entire rock has been replaced by a felt of sericite blades, patches of carbonate and quartz, and disseminated pyrite. Chemically, the altered rock has been enriched in potash, carbon dioxide, and sulfur, and depleted in soda, lime, and magnesia.

STRUCTURE AND ORE SHOOTS

One group of veins strikes N. 20°-60° E., averaging about N. 35° E., and another strikes nearly north. A few veins strike in other directions. The dip of the veins is mainly 70-80 degrees to the west and northwest, but some veins are vertical or dip steeply to the east. The veins are not distributed evenly in the area; the most conspicuous grouping on the map is an elongate belt extending with the trend of the constituent veins from Santa Rosita Mountain southwestward to Luceras Hill and beyond.

Most veins are traceable for only a few hundred feet, but others seem continuous for distances of 1,500-2,500 feet. Where veins terminate as individual features, offset veins, lying a short distance within the footwall or hanging wall, may extend farther on the same general strike. The veins are straight or broadly curved; in detail they follow slightly sinuous courses.

Many of the apexes are covered by a thin mantle of rocky debris, although here and there the veins may be traced for short distances by outcrops or float. Most of the surface exposures are in prospect pits, more or less widely spaced. As a result, the continuity of individual veins (pl. 3) is usually doubtful to some degree.

The shear zones that carry the veins have a maximum width of 16 feet. Widths of 1 to 6 feet are most common. Movement within these shear zones has taken place in several directions. The vein material usually occupies only part of a shear zone, so that in an average deposit the walls are sheeted and slabby for a few inches or feet on either side. Small parallel faults are present in the walls of some veins, but cross-faults are lacking. Zones of brecciation were seen in a few places. Where local bends occur in a vein, tight joints may branch into the wall. Only a few veins are branched, and the position of ore shoots appears to have no particular relation to the vein junctions.

Several types of ore bodies are present in the mines examined. In the Pennsylvania mine, ore occurs as thin tabular seams of coarse interlocking sphalerite and galena crystals, or as similar seams of crustified ore in which sphalerite, galena, quartz, and pyrite occur in parallel bands of almost pure mineral. The Tom Payne ore is similar but contains more quartz. In the Mina del Tiro deposit the ore shoot is an elongate lens of vuggy quartz, containing disseminations and thick streaks of galena and sphalerite. In the Franklin mine, galena and sphalerite occur without gangue as small masses and disseminations in a thick zone of highly sericitized monzonite porphyry. The other ore shoots probably originated largely by filling of narrow openings, to judge from the crustification, but ore in the Franklin mine has formed by replacement of the rock.

The largest ore shoots found in the district are apparently the one mined during 1945-1946 in the Pennsylvania mine and the one mined during World War I in the Tom Payne mine. The Pennsylvania shoot is at least 370 feet long and 220 feet deep, with ore thicknesses of a few inches to 3 feet, although locally the ore pinches out. The Tom Payne ore shoot is said to have been 300 feet long and 6 inches to 4 feet thick; it appears to have been at least 130 feet in dip length. According to available information, ore shoots in the Cash Entry and Marshall Bonanza mines were small.

The Tom Payne ore shoot may have been localized by a broad bend near the north end of the vein. The strike of the ore shoot is N. 15°20° E., whereas south and north of the ore shoot the vein strikes respectively north and about northeast and is relatively barren. No appreciable variations of dip were noted in the veins that would account for ore localization. The ore shoot in the Mina del Tiro is in a part of the vein that is characterized by slight wall-rock alteration and by strong brecciation rather than shearing.

OXIDATION OF DEPOSITS

The veins have been partly oxidized and leached to depths of 50-150 feet by surface waters moving downward to the water table along the relatively permeable channelways afforded by the veins. Sphalerite has been leached from the outcrops, and the zinc in part redeposited as the carbonate at lower levels in the zone of oxidation. Galena has been only partly leached; residual galena, partly coated with cerussite, is present within a few feet of the surface in a number of pits. The solution and redeposition of lead in the zone of oxidation is shown further by locally abundant wulfenite. The copper in the veins has remained largely in the gossans as colloform, botryoidal malachite or as rosettes of malachite needles. Azurite and chrysocolla have formed in minor amounts. Insignificant deposits of supergene copper sulfide may be indicated by blue films, possibly covellite, which locally coat galena crystals in the sulfide zone. Slender crystals of gypsum form drusy coatings in the ore and on the walls of recent mine workings.

At the surface the veins are generally stained in varying degrees by limonite and manganese oxides resulting from weathering of pyrite and ankerite. Where the sulfides, including galena, have been leached, a siliceous, highly cellular gossan remains. Chalcedony and opal occur as botryoidal linings in small cavities. The sulfuric acid liberated in the decomposition of pyrite has kaolinized the sericite of the wall rock.

No oxidized ore deposits were being mined at the time of the field work, and none was seen. Malachite ore has been mined in the past at the Evelyn property, and a little oxidized zinc ore has been taken from the Grand Central mine, but there are no records of the mining of oxidized zinc or lead ores in significant quantity.

The general barrenness of most veins at the surface has led miners to believe that leaching of ore minerals has been complete. This may be true locally, but the barrenness is mainly attributable to a lack of primary mineralization. Galena has been removed only partly, and it is believed that primary ore shoots that reach the surface can, in general, be detected in shallow pits by abundant residual galena. Other favorable signs in the appraisal of surface exposures of veins are an abundance of cellular quartz, heavy staining by manganese oxide, and the presence of oxidized ore minerals.

Mine Descriptions

MARSHALL BONANZA MINE

The Marshall Bonanza mine is in sec. 20, T. 15 N., R. 8 E., at the north end of the Cerrillos. The claim is the middle one of a patented group which also includes the Baca Bonanza and the Spiegelberg Bonanza. In 1945 the owner was the James W. Gerard estate, of New York City. The mine is said to have been worked from 1900 to 1906 by the Bonanza Mining & Milling Co., which shipped a few cars of ore and erected a mill on Bonanza Creek, 11/2 miles north of the mine. The Bonanza Copper Co. produced a little copper ore in 1917. Alec Mathieson, of Cerrillos, dewatered and timbered the workings in 1920. A few tons of zinc-lead ore was mined at that time, but none was shipped. In 1947 the Bonanza Trust Co. leased the property, installed pumps, and reconditioned and deepened the shaft. During 1948 and 1949 this company shipped a modest amount of ore to the smelter. The mine has been idle since 1950.

The vein, striking N. 30° E. and dipping steeply northwest, crosses a low knoll of hornblende monzonite porphyry surrounded by gravel and sand of the Ancha formation (pl. 1). On the surface, over a strike length of 250 feet, the vein has been explored by six shallow cuts and a pit 50-60 feet deep; the pit is situated a few yards north of the shaft. At the time of examination the only exposure of the vein was in this pit. Here the vein dips 83° NW. and tapers downward from a thickness of 10-20 inches to a thickness of 2-6 inches in a dip distance of 20 feet. It is composed largely of altered porphyry and quartz, stained with limonite. The walls are highly altered and sheeted parallel to the vein. The only visible ore lies in the dump from the shaft. Most of it is quartz, ankerite, and ferruginous rhodochrosite, with specks and bands of sphalerite, galena, and pyrite. Small quantities of malachite are present; hard steel-gray psilomelane, produced through oxidation of the manganiferous carbonate, forms botryoidal crusts on some of the ore.

The vein is opened by a shaft said to be 220 feet deep. From the 160-foot station, drifts extend 125 feet northeast and 175 feet southwest. The vein was reported to be 3-31/2 feet thick in these drifts and to contain small bunches of high-grade sulfide ore below the oxidized zone. Much water was present below the drift level. The vein was stoped from the drift upward to the bottom of the oxidized zone, 120 feet below the surface.

EVELYN PROPERTY

The Evelyn property, comprising the Brown, Evelyn, Manhattan, Santa Rosa, and Shannon lode claims, lies on the north slope of Santa

Rosita Mountain, at the north edge of the Cerrillos. The first recorded operators were W. H. and R. B. Paul, in 1910; the owner at that time was the Evelyn Gold-Copper Co. In 1912 the ownership had passed to Page Rodman and W. G. Franklin. The greater part of the production, probably amounting to 1,500-2,000 tons, was mined by Alec Mathieson and Joe Zucal in the late 1920's. The property has been idle since 1930. In 1945 it was reportedly under lease to W. Simonson, of Denver, Colorado, and Alec Mathieson, of Cerrillos.

According to available information, the ore shipped was a siliceous oxidized ore containing about 2½ percent copper as malachite and 0.2 ounce of gold per ton. The main ore body, which was mined in a small open pit at the collar of the Evelyn shaft, is said to have been 40 feet deep and 40 feet across.

The Evelyn property includes seven veins striking N. 30°-60° E. and dipping steeply to the northwest or southeast, in augite-biotite monzonite (pl. 1). The vein thicknesses range from 6 inches to about 5 feet. Only the gossans are exposed, which show altered rock and veinlets of quartz and chalcedony, highly stained with limonite and manganese oxide. Here and there a few specks of malachite, pyrite, and chalcopyrite are to be seen. The veins are opened by shafts, pits, shallow cuts, and three drifts and adits. The Evelyn shaft is said to be 247 feet deep, but it is inaccessible.

TRIO CLAIM

The Trio claim, in sec. 19, T. 15 N., R. 8 E., west of the Evelyn property, was staked in 1941 by Verne Byrne and Sam Carnes, of Santa Fe, but all the workings were excavated prior to 1941. The vein lies in a small inclusion of quartzite that is surrounded by augite-biotite monzonite and overlapped on the north by gravel of the Ancha formation (pl. 1). Ore occurs as a partial filling of small cracks in a weakly defined zone of fractures cutting the quartzite and striking N.10°15°W. The vein is opened by three 20-foot shafts spaced over a strike length of 48 feet and connected underground by a drift. Some stoping apparently has been done in the drift, although the workings could not be entered at the time of inspection. Other workings include three shallow cuts, two of them lying in porphyry and exposing no vein matter.

The only visible ore lies in small piles. Galena cubes with coatings of cerussite form clusters on quartzite. Some of the ore is composed of loosely aggregated small quartz crystals and galena cubes, with minor amounts of cerussite, limonite, and manganese oxide.

To the north and up the hill a few yards, a second vein, offset to the west from the Trio vein, is exposed in several pits, some of which were excavated partly in shale. Galena is present in some of the dump material.

TOM PAYNE MINE

The Tom Payne mine is in the SE¼ sec. 30, T. 15 N., R. 8 E. The original location was made about 1879. Lindgren (Lindgren et al., 1910, p. 167) visited the mine in 1905 and states that the shaft was 176 feet deep and that some ore already had been shipped. The earliest recorded ore shipments were made in 1911, when the property was owned by the Sunset Mining & Milling Co. At that time the mine was opened by a shaft with drifts at the 100- and 176-foot levels. In 1912 the mine was acquired by the Cerrillos Mining & Smelting Co., headed by G. L. Brooks, and operations were carried on intermittently from 1912 to 1918, during which period the greater part of the mine's total production was realized. Most of the ore was concentrated at the company mill near Cerrillos, where a 60-percent lead concentrate and 40-percent zinc concentrate were made by tabling. Only a few tons of ore was mined between 1919 and 1942. In 1942 the mine was leased by the present owner, H. 0. Brooks, to Andrew B. Stewart, of Albuquerque, who subleased the property to the Sierra Metals Co., of Pittsburgh, Pennsylvania. Ore mined during 1943 and 1944 was shipped to the custom mill of the American Smelting & Refining Co., at Hanover, New Mexico. Shipments of ore were made in 1949, 1951, and 1952. The recorded production for the period 1911-1952 was about 7,000 tons; the ore was high in zinc compared with the average for the district.

The mine lies at the north end of the Tom Payne vein as now known, which extends some 2,000 feet south to the Armington tunnel. The main shaft, inclining from 79 degrees to 86 degrees to the west, follows the vein to a depth of 310 feet below the outcrop. In 1945 levels connected with the shaft and developed the vein laterally both to the north and to the south. The first level, the floor of which is 102 feet on the incline below the shaft collar, is 820 feet long but at the time of examination was caved and inaccessible north of the shaft. From the ends of this level, air shafts ascend to the surface. The second level, at 175 feet depth, is 785 feet long; the third, at 271 feet, 330 feet long; and the fourth, at 295 feet, 60 feet long. Richard McGhee (oral communication), mine superintendent, reports that in 1951 a new level was opened at 250 feet, with drifts 125 feet to the north and south of the shaft. The vein is highly sheared, and close timbering of most of the drifts is necessary. Stopes were either backfilled or stulled. At least one stope had to be abandoned because of caving.

The workings and geology of the Tom Payne mine are shown in Plates 3 and 4A. The vein is a narrow zone, 1-10 feet thick, of sheared and hydrothermally altered monzonite containing thin tabular shoots and stringers of ore. The vein follows a slightly sinuous course; throughout most of its extent it strikes N. 10°-20° E., but on the second level, 220 feet north of the shaft, it bends more to the northeast. This curve coincides with the north end of the richest ore shoot mined. The dips are steep to the west, with reversal of dip indicated locally.

The ore is similar to that from other mines in the district, consisting mainly of coarse-grained sphalerite and galena occurring as massive sulfide ore or as coarse particles dispersed in a quartz gangue. Small blebs of chalcopyrite are present in the other sulfides.

The distribution of ore showings and stoped ground suggest that the ore shoots are elongate along the strike. The largest ore shoot, situated north of the shaft on the first and second levels, seems to have been continuous over a maximum strike length of 300 feet and a depth of at least 130 feet. This shoot does not appear on the third level and presumably terminates between the second and third levels. From this shoot, 3,000 tons of high-grade ore is reported to have been mined between the first and second levels during 1916-1918, and an additional 500-600 tons was mined above the first level, to within 40 feet of the surface. A second, smaller ore shoot has been mined on the second level, south of the shaft, over a stope length of 220 feet. Ore is present in the back of this stope at a few points, and the shoot perhaps extends above the first level at one place. Smaller shoots were mined on the three upper levels, some of them by the Sierra Metals Co. during 1943-1944.

Much of the remaining ore exposed is distributed in several widely separated parts of the mine and would be minable only at a relatively slow rate and high cost. The resumption of full-scale mining in the Tom Payne mine depends on the prior development of additional ore bodies by sinking and drifting.[2]

ANDREWS TUNNEL

The Andrews tunnel is in the NW¼ sec. 30, T. 15 N., R. 8 E., on the southeast flank of Santa Rosa Mountain (pl. 3). It is 225 feet long and follows a vein zone striking N. 5° E. to N. 18° W. and dipping 72° W. The vein zone is 6 inches to 5 feet thick and consists of sheared, altered monzonite containing a few stringers of quartz, veinlets of ankerite or siderite, and occasional streaks, blebs, and disseminated crystals of galena, pyrite, and sphalerite. From the portal to 30 or 40 feet short of the face, the vein is heavily stained with limonite. At the face, 115 feet vertically below the surface, the vein is unweathered; the vein zone is 2 feet thick and contains only 2-3 percent total of sulfides. Both walls are strongly chloritized over widths of 1-4 feet.

2. Editor's note: Since November 1955 the Western Development Co. has opened an ore shoot at the north end of the 200-foot level over a length of 60 feet and a maximum width of 3 feet. On December 15, 1955, the face was 460 feet from the shaft. Shipments from this area averaged 6.8 percent lead (0.1 percent nonsulfide), 13.3 percent zinc (0.25 percent nonsulfide), 2.14 percent silver, and 0.25 percent copper.

BOTTOM DOLLAR PROSPECT

The Bottom Dollar prospect is in Hungry Gulch, in the SW1/4 sec. 30, T. 15 N., R. 8 E. The property was owned by Reese P. Fullerton and Frank Staplin, of Santa Fe, in 1945, and was leased by Robert Hume. The workings include an old shaft 175 feet deep, with a 25-foot drift at the 150-foot level, said to show ore 5 feet thick. In 1944 Hume re-timbered the shaft to a depth of 130 feet. A small tonnage of ore was recovered at this time and stockpiled at the mine.

The Bottom Dollar vein may be continuous with one of the veins exposed in the vicinity of the Andrews tunnel (pl. 3). About 350 feet west of the shaft is a second, parallel vein, opened over a strike length of 720 feet by four pits. Ore is present in the dumps of two of the pits. Some of the ore consists of alternate bands of ankerite and sphalerite, containing minor amounts of galena and chalcopyrite. This vein, as well as the Bottom Dollar, appears to be a good prospect.

ARMINGTON PROPERTY

The Armington property is a patented claim in the SEI,4 sec. 30, T. 15 N., R. 8 E., adjoining the Pennsylvania group, which lies to the south. The claim is owned by John King, of Chicago, and is leased by the Cerrillos Lead & Zinc Co. The main workings (pl. 3) are the Arming-ton shaft and the Armington tunnel, both of which apparently were driven during the early days of mining in the Cerrillos district. The shaft, reported to be 150 feet deep, is flooded to a level 80 feet from the surface. The discovery shaft, a few yards to the south, is 29 feet deep. A vein is said to pass through the two shafts, but as both are timbered, nothing could be seen of the geology. The vein possibly may be a branch of the Pennsylvania vein, but more probably it is a separate body, parallel in strike but lying to the west of the Pennsylvania. No vein can be traced between the shafts and the Armington tunnel, 460 feet to the north.

The Armington tunnel extends 345 feet north on the Tom Payne vein from a point which apparently is near the south end of the vein. From the portal to the face of the tunnel, the vein is a band of altered monzonite 1-6 feet thick, containing a few small quartz stringers, copper stains, and much iron and manganese oxide. Weathering is conspicuous at the face, which is 130 feet vertically below the surface.

PENNSYLVANIA MINE

The Pennsylvania mine is in the NW ¼ sec. 31, T. 15 N., R. 8 E., on a tributary of Hungry Gulch. The Pennsylvania group comprises the Bob Ingersoll, J. B. Weaver, Bertha Mable, Owl, and Sure Winner claims, some of which are among the oldest locations in the district. The mine shaft is on the northernmost of the claims, the J. B. Weaver, about 90 feet from the north end line. At the time the claims were patented, about 1915, the shaft had been sunk to a depth of 150 feet by the owner, Michael O'Neill, and ore had been found at a depth of 80 feet. During 1917-1918 John W. Beard leased the mine and reportedly shipped several carloads of ore. In 1934 the American Metal Co. performed a little exploratory work and retimbered part of the shaft. The present operator, the Cerrillos Lead & Zinc Co., started working the Pennsylvania mine in October 1942. Verne Byrne, of Santa Fe, is the property owner and also manager of the operating company. During 1942-1945 the shaft was deepened to the 189-foot level, drifts were driven north and south, and three stopes were opened. Late in 1945 the shaft was extended to the 300-foot level. Ore was shipped to the custom mill of the American Smelting & Refining Co., at Hanover, New Mexico. Approximately 900 tons of lead-zinc ore of good grade was produced between 1942 and 1952.

On the surface the Pennsylvania vein is traceable in pits and shafts for a distance of about 650 feet (pl. 3). One of the pits is reputed to be an old Spanish working. The vein strikes about due north on the average and dips 70°-80° W. Near the Pennsylvania shaft it bends abruptly, and the bend is reflected also in the course of the vein underground. In the saddle south of the mine, a conspicuous vein is exposed in pits dug on the east flank of Luceras Hill; this may be a faulted segment of the Pennsylvania vein or, more probably, a second vein. In the surface workings, the Pennsylvania vein is a band of light-colored, soft, altered augite-biotite monzonite, 1½ -7 feet wide, containing streaks of limonite and narrow stringers of quartz. Galena was found in one of the pits, and green botryoidal smithsonite reportedly was found in the weathered capping of the vein during early operations.

The underground workings, shown in Plate 4B, include a steeply inclined shaft; the 189-foot level, which opens the vein over a strike length of 405 feet; and three stopes. The vein as exposed in these workings is a thin, sinuous zone of shearing and alteration which, at most points, contains a band of massive sphalerite and galena lying in the middle or on the footwall or hanging wall. Streaks of white massive opaline silica are locally interlayered with the ore. The sulfide ore forms elongate tabular bodies ranging from a few inches to 3 feet in thickness. In detail the bands of ore are discontinuous along strike and dip; considered more broadly, they form a thin, pinching and swelling ore shoot that extends from a point 80 feet below the collar of the shaft to the 300-foot station, and from end to end of the 189-foot level. In the shaft between the 189-foot and 300-foot levels, the vein contains an almost continuous band of massive ore ranging from 6 to 18 inches in thickness. Several carloads of high-grade ore were recovered in the process of shaft sinking. At the time of examination, the reserves of readily minable ore appeared to be larger than those in any other mine in the district. In depth the ore shoot has not been bottomed; possibly it may be found to continue laterally to the north or south, although the vein at both ends of the 189-foot level is but weakly mineralized. The vein splits at the north end of the level. The split may be local. On the other hand, the west branch possibly may connect with the vein that passes through the Armington shaft to the north, although no evidence of such a connection was found at the surface.

Shearing in the vein has been intense and has occurred along several different planes of movement. The bands of ore are, however, unfractured. The chief alteration is sericitization, but chloritization has occurred at points more distant from the vein.

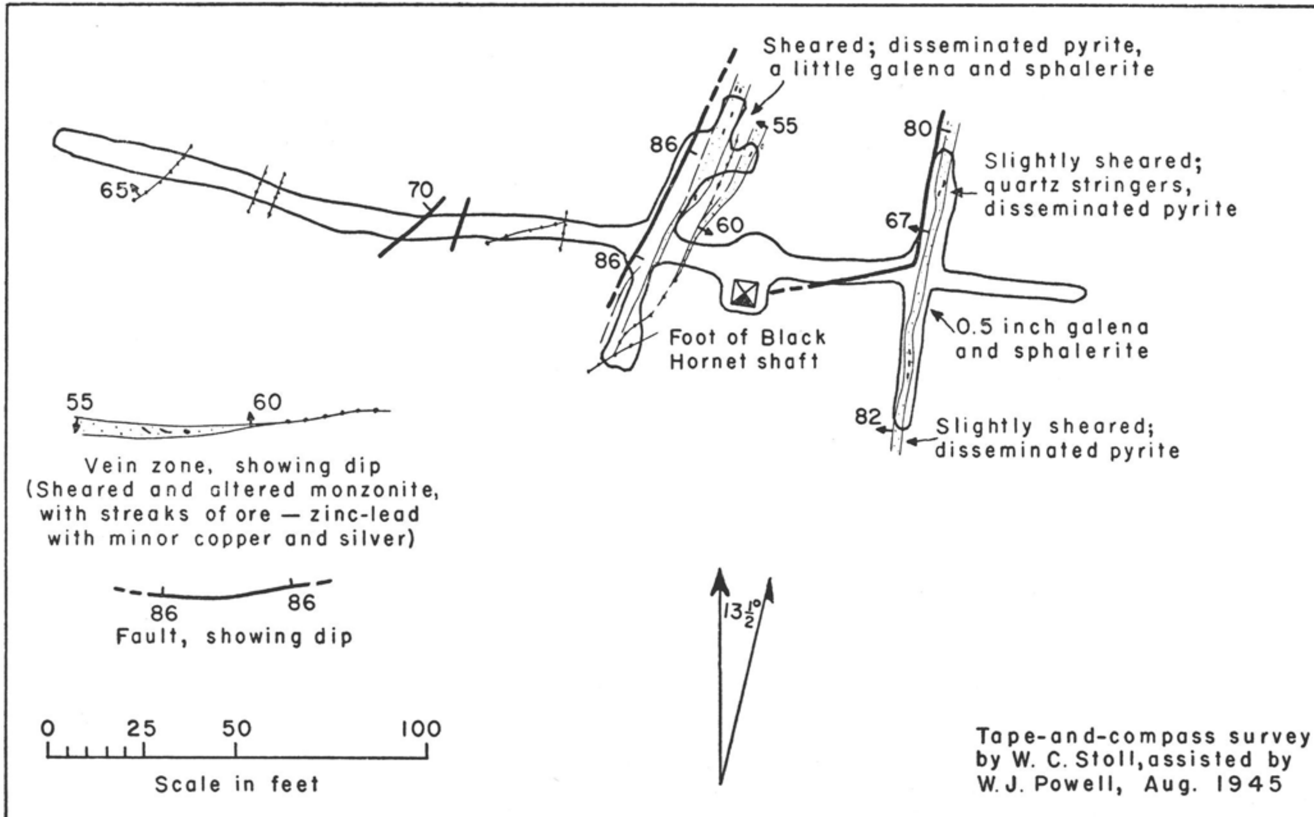
The ore has been mined by both overhand and underhand stoping. Stopes were carried at a minimum mining width of 4 feet, and so the ore and adjoining sheared wall rock were blasted together. The ore was handsorted and the waste backfilled on timbered drifts.

BLACK HORNET PROSPECT

The Sierra Metals Co., as part of a program of exploration and development in the Cerrillos district, sank the Black Hornet shaft in 1944 in the SW¼ sec. 30, T. 15 N., R. 8 E., about 2,000 feet west of the Pennsylvania shaft. Reese Fullerton and Frank Staplin, of Santa Fe, are the property owners. The shaft was sunk vertically to a depth of 100 feet, and short crosscuts were run east and west. Development was in progress during the fall and winter of 1945 under the direction of Richard McGhee, mine superintendent. A well had been drilled to the water table at a depth of 175 feet below the floor of Hungry Gulch, and a flotation mill was under construction. The surface features in the vicinity of the Black Hornet prospect are shown in Plate 3, and a plan of the workings at the foot of the shaft in Figure 6.

The country rock is augite-biotite monzonite. Two thin veins, neither of which appears at the surface, were intersected on the 100-foot level and were opened by drifting to the north and south. The east vein strikes N. 9° E. and dips steeply west. It is a zone of slightly sheared and altered rock 1-3 feet thick, containing quartz stringers and disseminated pyrite. A small solution cavity containing crystals of amethystine quartz was noted, and a little sphalerite and galena are present in some of the quartz stringers. The west vein strikes N. 24° E. and has a variable dip. It consists of several parallel planes of shearing, between which the monzonite has been highly altered and lightly mineralized with pyrite, quartz, and carbonate, including a little pale-pink rhodochrosite. A small pocket of coffee-colored sphalerite, with minor amounts of galena,

Figure 6



GEOLOGIC MAP OF 100-FOOT LEVEL, BLACK HORNET PROSPECT.

was found at one point. No ore had been developed on either vein at the time of examination.

CASH ENTRY MINE

The Cash Entry mine lies mainly on the Cash Entry claim, in the SE1/4 sec. 5, T. 14 N., R. 8 E. The property is one of the earliest locations in the district. The first operator appears to have been the Boston-New Mexico Mining Co., which is said to have sunk the Cash Entry shaft and driven many of the underground workings.

At the time of Lindgren's (Lindgren et al., 1910) visit in 1905, the mine had been idle since 1904 and was filled with water to a level 150 feet below the surface. Subsequently it was unwatered. From 1909 to 1915 the property was owned and operated by the Boston-Cerrillos Mines Corp. An appreciable production is recorded for the years 1909 and 1910, part of which is supposed to have come from the Cash Entry No. 3 shaft, on the Franklin vein. For the period 1911-1915 no production is recorded, and Bureau of Mines data indicate that the Cash Entry mine was closed in January 1915 on account of water. At the time it was closed, mining reportedly was in progress on the 450-foot level, and the inflow of water was about 250 gallons per minute. The mine has remained idle since 1915. John W. Beard, of El Paso, Texas, is the present owner of the Cash Entry, Franklin, Grand Central, and adjoining claims, and has leased the property, totaling some 420 acres, to the Moline Mining & Milling Co., of which John Reba, of Santa Fe, is general manager.

The Cash Entry mine has been one of the most productive mines in the district. According to John W. Beard, the present owner, about 500 tons of rich silver ore, with values in gold and copper, was produced in 1886, and 4,500 tons of lead-zinc ore was produced in 1890-1903. During the period 1909-1952 about 9,000 tons of lead-zinc ore was mined from the Cash Entry, Grand Central, Franklin, and other nearby properties.

A map of the Cash Entry is shown in Plate 5, which is a copy of an old mine map made by the Boston-New Mexico Mining Co., the earliest operator. The shaft is vertical and is said to be 650 feet deep. The upper level, not shown on the map, is reported to be 126 feet below the collar. Underground the vein appears to follow an irregular course. On the surface it strikes N. 40° E. and is traceable in the shaft and in deep, closely spaced pits over a length of about 250 feet. Probable further extensions are covered with debris. The country rock is slightly sericitized and epidotized hornblende monzonite porphyry. According to Lindgren (Lindgren et al., 1910, p. 167):

> The deposit is a well-defined shear-zone vein with several good walls distributed within a width of about 15 feet; evidently it is of the type of replace-

ment veins. Down to water level the ore was oxidized with residual masses of galena and much zinc carbonate. Sulfide ore was entered at water level. The fresh ore occurs in a gangue of ankerite and quartz and contains galena, yellow zinc blende, and a little chalcopyrite. It is only moderately rich in silver, containing about 20 or 30 ounces to the ton. In depth zinc ores are said to prevail. Near the vein the country rock is partly converted to sericite; tourmaline is also present in some of the specimens.

GRAND CENTRAL MINE

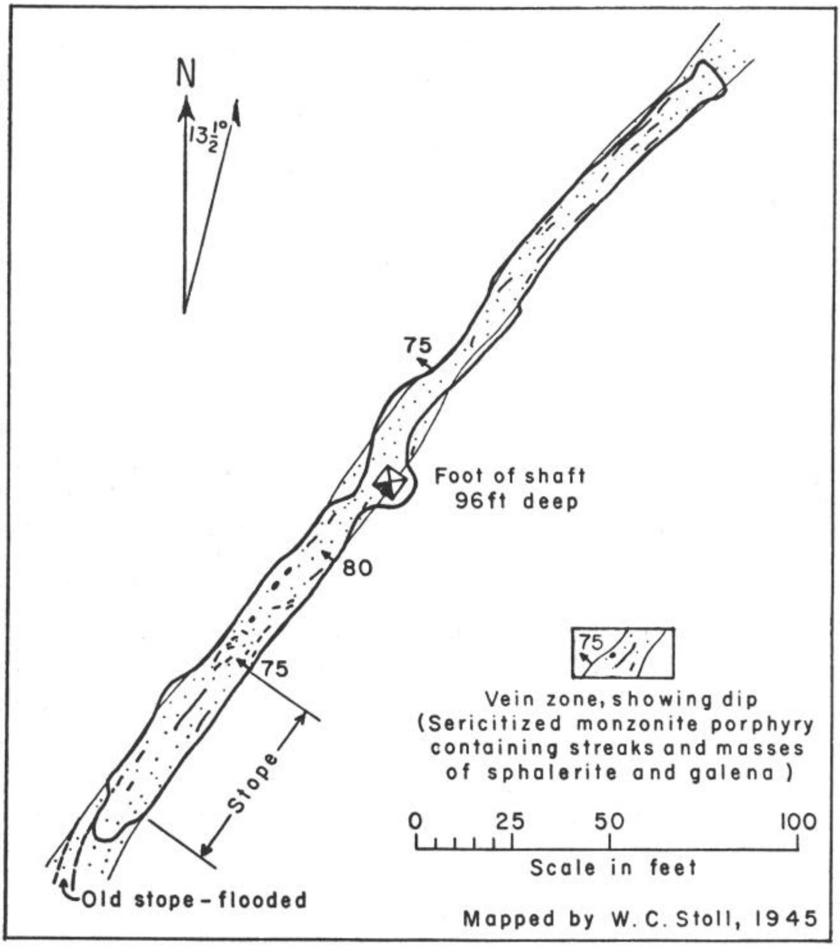
The old Grand Central workings lie 1,300 feet west of the Cash Entry shaft, in the SE1/4 sec. 5, T. 14 N., R. 8 E. The vein on the surface is traceable, though discontinuously, for 500 feet in pits and in the shaft. It strikes N. 30° E., roughly parallel to other veins in the vicinity. The visible parts of the vein are thin bands of altered monzonite porphyry, stained with limonite and manganese oxide.

The mine is flooded; it is reported to be 500 feet deep and to have stopes. According to Mr. John W. Beard (oral communication), the mine produced 4,800 tons of ore during 1890-1893, averaging 4 ounces of silver per ton, 7 percent lead, and 18 percent zinc. Lindgren (Lindgren et al., 1910, p. 167) relates that in 1905 efforts were made to sort and ship oxidized zinc ore from the upper levels. At one time the mine employed many men and reputedly was the largest ore producer in the district. After the shaft housing and mill burned down in 1918, the mine was idle until 1951. During 1951 and 1952 small tonnages of ore were shipped from the upper levels. In 1952 the mine was under lease to the Moline Mining & Milling Co.

FRANKLIN MINE

The Franklin claim adjoins the Cash Entry on the west. During 1909-1910 considerable rich ore is said to have been mined from the Cash Entry no. 3 shaft, on the Franklin vein. The operator was Dockweiler, who reportedly shipped 5 or 6 carloads of high-grade lead-zinc ore from an ore shoot 6-7 feet thick and 80 feet long. The shaft was flooded later by water pumped from the Cash Entry mine.

The Franklin shaft, started from the bottom of a 25-foot prospect pit, was sunk to a depth of 96 feet by John Reba and Alec Mathieson in 1943. Drifts were driven 135 feet northeast and 120 feet southwest on the vein at the 90-foot level. The southwest drift connects with old stopes from the Cash Entry no. 3 shaft, now inaccessible. A small stope was opened in the southwest drift, and about 1,500 tons of low-grade ore from this stope and from development was milled in the rebuilt Cash Entry mill during 1945-1946. A zinc concentrate containing 49 percent zinc and a lead concentrate containing 63 percent lead, according to preliminary assays, were produced by flotation. The zinc



GEOLOGIC MAP OF 90-FOOT LEVEL, FRANKLIN MINE.

Figure 7

concentrate is reported to have contained a little cadmium. Between 1946 and 1952 the only mining appears to have been in 1949, when about 500 tons was produced. In 1952 the mine was under lease to the Moline Mining & Milling Co.

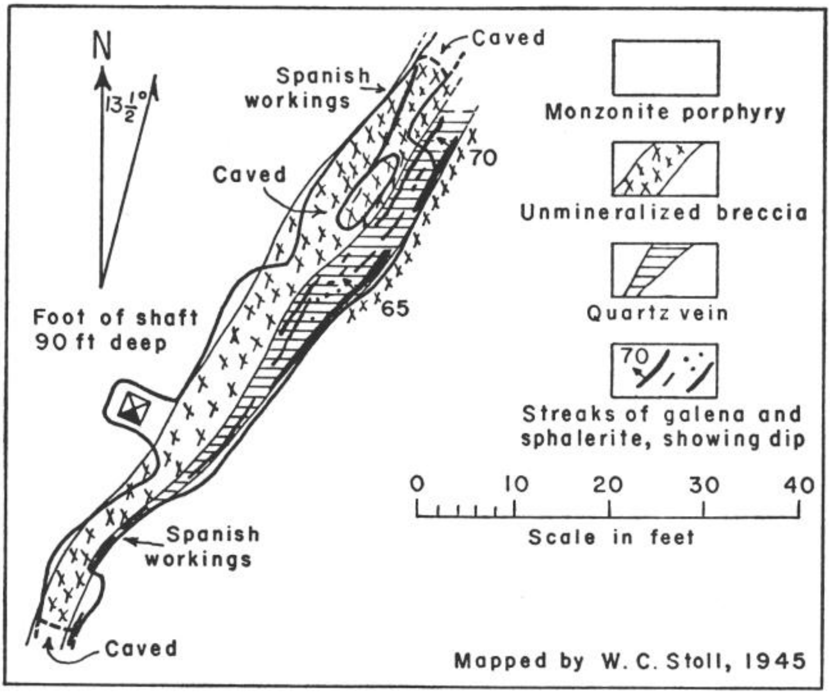
The geology on the 90-foot level is shown in Figure 7. The vein strikes N. 38° E. and dips 75°-80° NW. The ore shoot exposed in the drift is unlike other ore shoots seen in the district. Coarse galena and sphalerite occur as small lenses, rounded masses, and disseminated crystals in a zone of highly sericitized hornblende monzonite porphyry. Gangue minerals are scarce. Shearing has been very slight; the soft, highly sheared rock characteristic of most of the veins in the district is absent. The limits of the ore shoot are determined only by the localization of the sulfides, no distinct walls being visible in the workings. Limonite and manganese oxide are abundant, but the ore minerals are quite fresh on the 90-foot level. In the shaft a few pieces of residual galena were found in the vein up to a point about 30 feet below the surface.

MINA DEL TIRO

The Mina del Tiro is in the NW¼ sec. 8, nearly a mile southwest of the Cash Entry mine (pl. 1). Two old shafts, which form part of the mine workings, were found by the earliest American prospectors; Jones (1904, p. 30) believes that this work was performed prior to 1680 by Indian slaves under the direction of the Jesuits. In modern times the mine has produced only a little ore. About 1910 a vertical shaft was sunk 90 feet in the hanging wall of the vein, and a carload of ore reportedly was mined. Another carload is said to have been taken out by Jones and Davis in 1933-1934. Since 1938 the property has belonged to Verne Byrne, of Santa Fe. A mill-test lot was mined and shipped in 1942, but no work has been done since that date.

On the surface the vein is traceable for 1,300 feet, although not continuously. It strikes N. 45° E. and dips steeply northwest. The country rock is a moderately sericitized hornblende monzonite porphyry. Both the Spanish and the modern workings lie near the northeast end of the vein. One of the ancient shafts apparently was sunk as deep as 90 feet vertically on the vein, but it is now completely filled. The other appears to have been an incline descending in steps to a shallow depth; it was not examined by the writer but is said to be largely filled with silt. The recent shaft was sunk between the two Spanish workings, and a short drift was driven on the vein, intersecting old workings on both the northeast and the southwest. The geology of the accessible part of the mine is shown in Figure 8.

The main ore shoot underground, exposed for a length of 55 feet, is a lens of vuggy white quartz containing thick streaks and disseminations of galena and sphalerite. Some of the sphalerite is olive green. The ore



GEOLOGIC MAP OF 90-FOOT LEVEL, MINA DEL TIRO.

Figure 8

lies on the footwall of a tabular breccia zone composed of angular unrotated fragments of wall rock 1-6 inches across. Little hydrothermal alteration is apparent. The ore is heavily stained with limonite, but the lead and zinc sulfides are affected only slightly by weathering. Wulfenite is abundant as small, square, tabular yellowish-gray crystals, which form a coating on the primary ore in cracks and vugs.

A second ore streak, 8 inches wide and composed of quartz and galena, lies a few feet within the hanging wall of the main shoot. It is followed by the Spanish workings at the northeast end of the drift.

Economic Aspects

The past history of the district should provide sufficient indication of what may be expected in future mining. The principal producing veins have been explored to depths of 96-650 feet below the outcrops during the last 75 years of mining. All known ore shoots are small, although some of the run-of-mine ore is high in grade. The walls of ore shoots are commonly weak and slabby, and require timbering of drifts and close stulling or filling of stopes. Where mining descends below the water table, at depths of 100-300 feet below the surface, pumping or bailing is necessary. The close association of sphalerite and galena makes milling necessary, but the small size of the deposits does not justify a large mill. As may be judged from these facts, operational costs are comparatively high.

Underground development should be preceded by thorough surface trenching and pitting, to determine the existence and possible extent of the ore. Oxidation of the veins makes it necessary to sink or drift for considerable distances before reaching the zone of primary sulfides. Perhaps the best exploratory method for new veins would be diamond drilling to points below the oxidized zone, after surface prospecting has revealed favorable indication of ore.

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