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Geology of the Northern Caballo Mountains

Sierra County, New Mexico

Submitted to

The Geology Department

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of

Mining and Technology

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by

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ABSTRACT

The center of the 150 square miles that constitute the northern Caballo Mountains area is about seven miles southeast of the town of Truth or Consequences (formerly Hot Springs), New Mexico. It is served by State Route 52, and by a few poorly-graded gravel roads. The vegetation consists mostly of shrubs and is very sparse. The topography is made up of plains and slopes, cut by dendritic drainage patterns in the youthful stage of a semiarid cycle, with the north-south trending ridge of the Caballo Mountains separating the area into two parts.

The oldest rocks in the area are represented by Precambrian quartzites and schists which were later cut by igneous intrusions (predominantly granite). The sedimentary sequence consists of the Bliss quartzites, sandstones, and sandy limestones of the Upper Cambrian; the El Paso and Montoya limestones and sandstones of the Lower and Upper Ordovician; the Magdalena limestones and shales of the Pennsylvanian; the Abo red beds and the Chupadera limestones, sandstones, and evaporites of the Permian; and the Dakota sandstone, Mancos shale and Mesaverde interbedded sandstones and shales of the Upper Cretaceous. Tertiary and Quaternary sediments consist of conglomerate, grading upward into partially consolidated sands and gravels that have arbitrarily been named the T C (Truth or Consequences) formation.

The structure consists of northwestern-southeastern trending folds, and three groups of faults which are classified according to their

general directional trend: a northwest-southeast group, a north-south group, and an east-west group. Evidence in the field does not justify dating the initial folding and faulting earlier than post-Mesaverdean, and does indicate that movement took place as late as the Quaternary period.

Fluorspar is the only important ore deposit; however, more accessible, better developed, and more strategically located fluorspar mines fill the present limited demand. Minor amounts of copper, lead, and vanadium ores have been found. Apparently all deposits are fissure veins which have been formed by replacement and/or space-filling processes which followed the post-Mesaverdean faulting.

The extreme eastern part of the area has the necessary structure and is underlain by possible source beds and reservoir rocks for local accumulation of petroleum.

GEOLOGY OF THE NORTHERN CABALLO MOUNTAINS

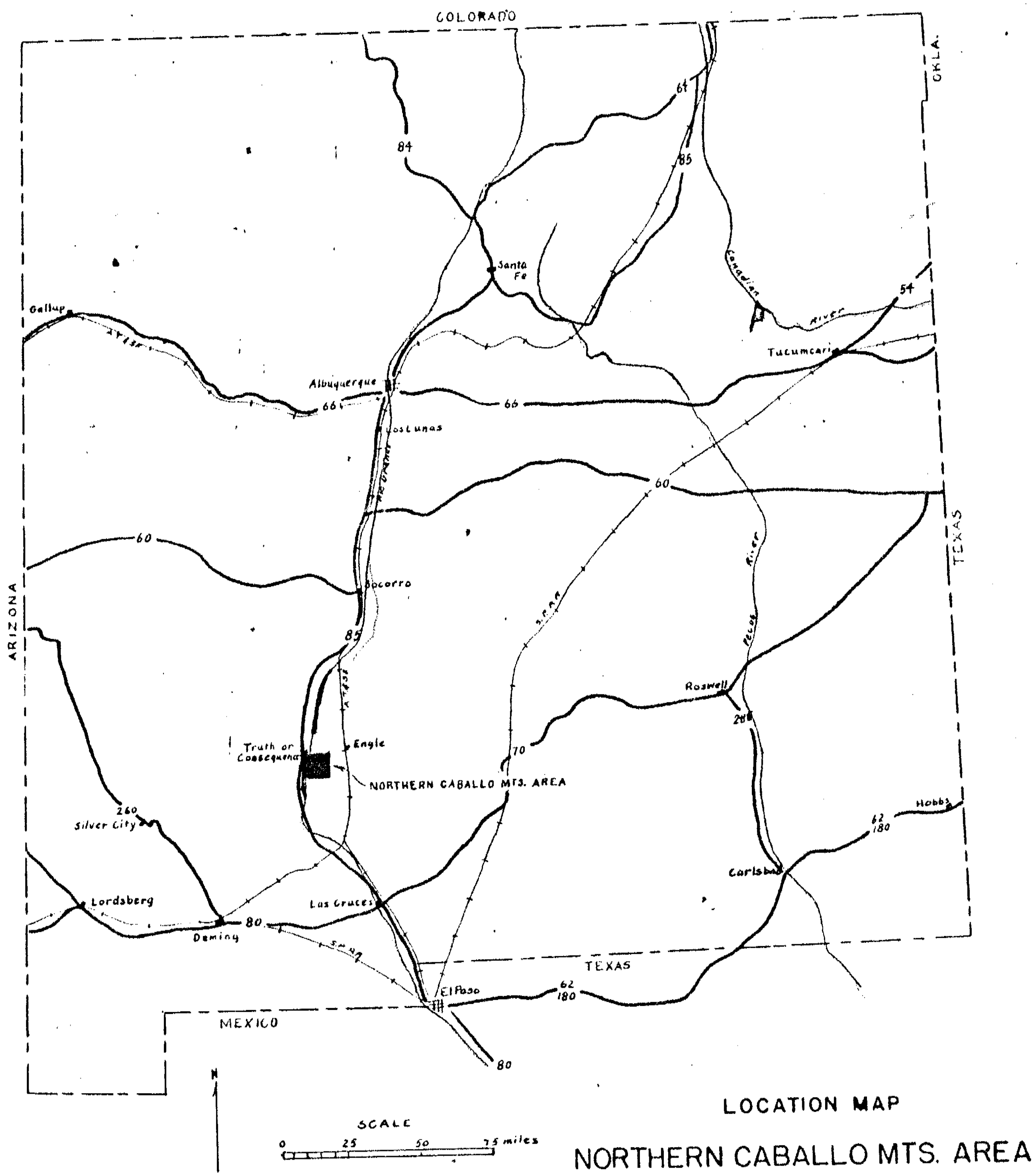
SIERRA COUNTY, NEW MEXICO

INTRODUCTION

Location and Accessibility.

The northern Caballo Mountains area covers about 150 square miles in southwestern New Mexico: the center of the area is approximately six miles southeast of the town of Truth or Consequences, formerly known as Hot Springs. (Pl. 1; and pl. 16 in pocket.) The area comprises R. 4 W., T. 14 S; R. 3 W., T. 14 S; R. 4 W., T. 15 S; and R. 3 W., T. 15 S., New Mexico Principal Meridian, and the southern part of the Pedro Armendaris Grant as far north as the Rio Grande and State Route 52.

The area is served by State Route 52, which extends east from Truth or Consequences across the northern boundary of the area to Engle, New Mexico. This road is macadam from Truth or Consequences to about one mile east of Elephant Butte Dam; the remainder is a well-graded, all-weather, gravel road. The roads extending south from State Route 52 are very narrow and are not graded except where they cut into slopes. They are poorly drained and consequently washouts are common after summer flash floods. These roads were maintained by government funds during World War II when several mines in the area were in operation, but have deteriorated since mining activity was shut down after the war. However, all roads have solid beds and can be easily repaired and maintained.



LOCATION MAP

NORTHERN CABALLO MTS. AREA

PLATE I

J C Doyle

The Albuquerque and El Paso branch of the Atchison, Topeka and Santa Fe Railway Company runs through Engle and has in the past been the means of shipping ore from the area to smelters and mills in El Paso, Deming, Los Lunas and San Antonio.

Purpose and Field Methods.

The purpose of this report is to gain a more detailed geologic understanding of the area than that compiled by Darton (1928) in his early reconnaissance of New Mexico, and to fulfill the requirements for a master of science degree.

The areal geology was plotted in the field on vertical photographs. Geologic details were transferred with a radial planimetric plotter and a focalmatic projector to the planimetric map used as a base. The photographs, obtained from the Soil Conservation Service in Albuquerque, have an overlap of 60 percent and a sidelap of 30 percent. Strikes and dips were determined in the field with a Brunton compass. Thicknesses of members and formations were determined by four methods: by Brunton compass method (Lahee, 1941: pp. 425, 426); by direct measurement with a steel tape; by plane table and alidade; and by determining elevations with an aneroid barometer, attitudes of beds with a Brunton compass, and scaling the widths of outcrop belts after the various points were plotted on the planimetric map.

The present report is based upon about 120 days' field work by the author, and about 20 days' supervision by the staff of the Geology Department of the New Mexico Institute of Mining and Technology.

Previous Work in the Area.

No single prior publication describes in detail the general geology of the northern Caballo Mountains area. C. R. Keyes (1903 and 1905) gave a brief description of bolson gravels, Cretaceous sediments, and basic lava flows that are found in the eastern part of the area. C. H. Gordon and L. C. Graton (1906) compared lower Paleozoic formations of the Caballo Mountains near Shandon mining camp with similar formations at Silver City and Lake Valley. W. T. Lee (1907) discussed essentially the same subjects as Keyes in connection with water supply and irrigation. Lee also compared the "Manzano group" of the Caballo Mountains with other sections of the Rio Grande valley (1909). Several articles on the geology and operating problems of vanadium deposits in the area were written by B. Leatherbee (1910), E. D. Johnson (1911), P. A. Larch (1911), C. A. Allen (1911), J. O. Clifford (1911), and Frank L. Hess (1917). A brief, general description of all ore deposits in the area was made by Waldemar Lindgren, L. C. Graton and C. H. Gordon (1910). N. H. Darton (1918) compared the Paleozoic section of the area with sections of other areas in southern New Mexico, and later (1928) made a reconnaissance map and gave a general geologic description of the area. W. D. Johnston (1928) and H. E. Rothrock, C. H. Johnson and A.D. Hahn (1946) described in detail the fluorspar deposits of the Caballo Mountains. G. T. Harley (1934) compiled much of the above mentioned publications into a single bulletin. Dr. Vincent C. Kelley of the University of New Mexico has recently completed a general geologic report and map (unpublished) of the area around Truth or Consequences which include the northern Caballo Mountains area.

Acknowledgements.

Special acknowledgement is due the faculty of the Department of Geology, New Mexico Institute of Mining and Technology, Drs. John E. Allen, Clay T. Smith, and Stewart M. Jones, who accompanied the writer in the field on several occasions and who gave valuable suggestions and advice concerning various geologic problems in the field and also in the compilation of this report. Dr. Eugene Callaghan, Director of the New Mexico Bureau of Mines and Mineral Resources, furnished transportation and made available drafting facilities in his department. Alan H. Cheetham, New Mexico Institute of Mining and Technology, assisted in detailed measurements of the Pennsylvanian system and he checked part of the writer's fossil identification of species collected from the different formations.

Physical Conditions

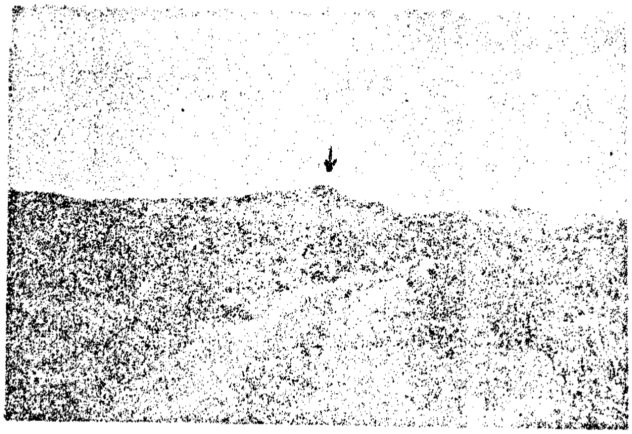
Topography, Drainage and Relief.

The northern Caballo Mountains area can be divided into four general topographic features: The bolson portion of a pediment, a nearly flat plain along the eastern margin and in the southeastern part of the area; the rejuvenated portion of this pediment, irregularly capped with lava, of eastward-dipping sediments west of the bolson deposits; the youthful ridge of the Caballo Mountains proper; and the complex westward-sloping terraces that extend from the base of the range, westward to the Rio Grande and the Caballo Reservoir.

An extensive bolson forms the western edge of the Jornada del Muerto (Journey of the Dead), so named by travelers who crossed this desert valley before the advent of the railroad. The Jornada del Muerto (pl. 2, C) is an arid plain that extends north and south for 120 miles and is about 25 miles wide in the vicinity of the Caballo Mountains. Drainage of the bolson is toward the east. The plain is slowly being dissected and many isolated islands of underlying sedimentary rocks have been exposed.

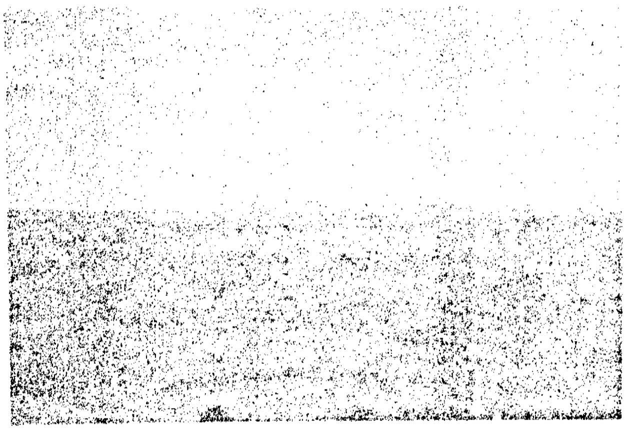
A flat surface, beveled on a series of eastward-dipping beds, rises westward on a very gentle slope from the western edge of the bolson deposits (approximately 5,000 feet above sea level). This surface was partly covered by a sheet of lava (pl. 3, D) and later rejuvenated by lowering of the Rio Grande valley. The eastward-dipping interbedded shales and sandstones were readily attacked by small subsequent intermittent streams as soon as the protecting lava sheet was removed. The present surface consists of a series of cuestas (pl. 3, B) that extend westward from the Jornada del Muerto to the foot of the mountain range, with here and there traces of the old flat pediment (pl. 3, C) which are, in some instances, still capped with remnants of the lava sheet.

The Caballo Mountains are essentially a long ridge, extending north and south through the area, bounded on the west by a steep fault-line scarp and bounded on the east by a gentle slope. The ridge has a sharp knife-like

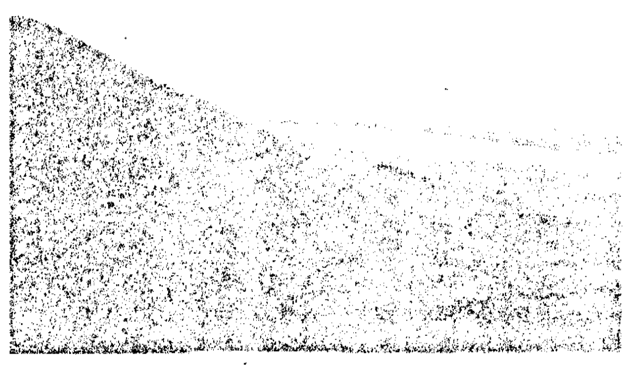


A. Looking west toward Brushy Mountain.

B. Looking east toward Turtle Peak.

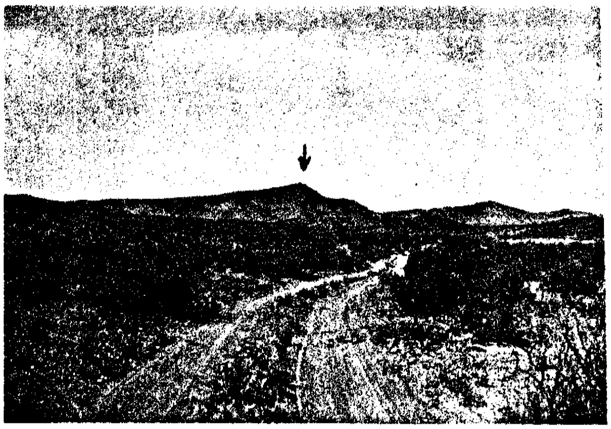


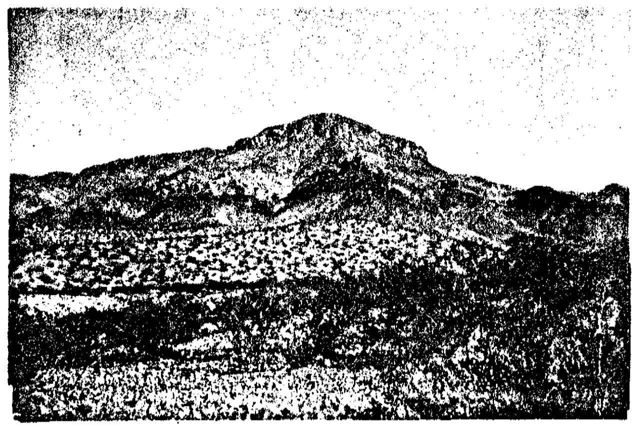
C. Jornada del Muerto with San Andres range in distance.

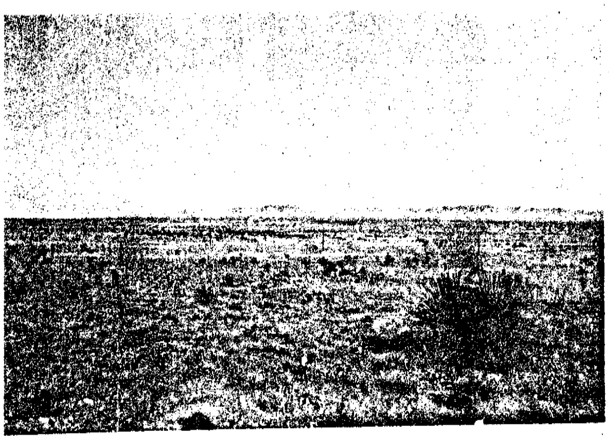


D. West entrance to Palomas Gap.

Plate 2.







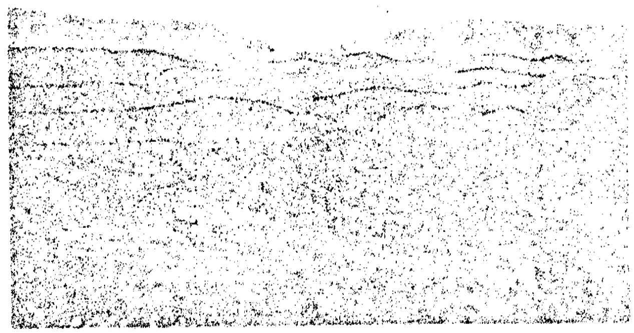
restline locally broken by gaps caused by transverse faulting and erosion. he ridge in the area is separated into two parts by Palomas Gap (pl. 2, D), deep arroyo that drains most of the area south and east of the range to he edge of the bolson area. The northern half culminates in the middle in urtle Peak (pl. 2, B) at 6,400 feet. The southern part of the range has a airly horizontal crestline from Palomas Gap to Longbottom Canyon, but outh of Longbottom Canyon the range has been faulted up to form rushy Mountain (pl. 2, A) with an elevation of about 8,000 feet, the highst point in the area.

The westward-sloping terrace surfaces in the western part of the area, which are preserved by caliche and cemented gravel, have an inclination of from 3 to 10 degrees. They are drained by a series of parallel arroyos into the Rio Grande and the Caballo Reservoir, at an elevation of approximately 4,200 feet. (Pl. 3, A.) These terraces or outwash alluvial slopes are interrupted north of Palomas Gap by rounded hills and hogbacks (of igneous and sedimentary rocks) resulting from step faulting.

Vegetation.

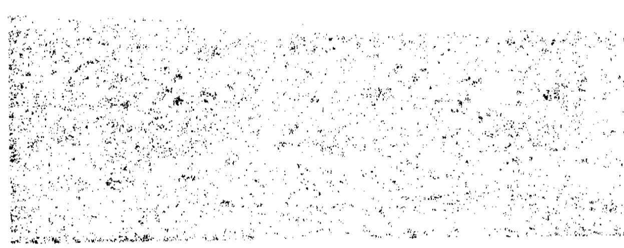
The vegetation zones of the area range from the Lower Sonoran zone to the Transition zone, and consist of creosote bush (Covillea glutinosa, Lower Sonoran); mesquite (Prosopis juliflora, Lower and Upper Sonoran); cholla (Opuntia sp.); ocotillo (Fouquieria splendens, Lower Sonoran); prickly pear (Opuntia sp.); sotol (Dasylirion wheeleri, Lower and Upper Sonoran); Spanish bayonet (Yucca baccata, Upper Sonoran); soapweed or

A. Westward sloping terraces. Truth or Consequences in the distance.



B. Palomas Gap from the east. Lines represent east-dipping cuestas.

C. Remnants of the Tertiary pediment.



D. Slightly dissected pediment with Caballo Cone and flow.

Plate 3.

pamilla (*Yucca elata*, Lower Sonoran); century plant (*Agave americana*, Lower and Upper Sonoran); and range grass (*Panicum* sp.). In addition to these species, hackberry (*Celtis reliculata*, Upper Sonoran) and canyon live oak (*Quercus wislizenii*, Transition) are found in the canyon bottoms. Brushy Mountain was named for its dense cover of juniper (*Juniperus utahentis*, Upper Sonoran) and piñon (*Pinus edulis*, Upper Sonoran). Cottonwood (*Populus* sp.), salt cedar (*Tamarix gallica*) and willow (*Salix* sp.) form thick cover along the banks of the Rio Grande. With the exception of Brushy Mountain, the Rio Grande, Ash Canyon and Mescal Canyon, the vegetation of the area is very sparse, but does, however, afford grazing for seven head of stock per section, under the Taylor Grazing Act. Most of the species of plant life are scattered indiscriminately over the area, and no correlation was discovered between plant and formational distribution.

Climate.

The mean annual precipitation at Engle, 11 miles east of Elephant Butte Dam, is 9.89 inches, and the mean annual temperature is 59.9 degrees. 1/ The greatest precipitation occurs in late summer and early fall and is usually in the form of thundershowers and cloudbursts. Light snowfalls cover the higher mountains in the winter but rarely remain longer than a day. In the higher parts of the area, the average temperature is lower and the mean annual precipitation is greater than at the weather station in Engle, based on the experience of the writer.

1/ Hill, Kenneth, U. S. Weather Bureau, Socorro, New Mexico: 1950.

GEOLOGY

Stratigraphy

The northern Caballo Mountains area is composed of rocks ranging from Precambrian basement complex to Recent caliche, sands and cemented gravels. Precambrian rocks consist of metamorphosed sediments and igneous intrusives. Sedimentary rocks include the Cambrian, Ordovician, Pennsylvanian, Permian, Cretaceous, Tertiary and Quaternary systems. Post-Cretaceous igneous rocks are represented by dikes, sills, and extrusives.

Lithology and paleontology of the Cambrian and Ordovician rocks are shown on plate 5; the Pennsylvanian on plate 6; the Permian on plate 7.

Fossil collection points and locations of measured sections are shown on plate 17, in pocket on back cover.

The earlier Paleozoic formations, from Cambrian through Ordovician, have as their type section the Franklin Mountains, a north-south trending range just north of El Paso, Texas; however, the exact location in the Franklin Mountains of the section or sections (Richardson, 1904, p. 27 and 1908, pp. 476-479) is not specified. The writer visited the Franklin Mountains and accurately located on a map a complete section (pl. 4) for the purpose of comparing the Cambrian and Ordovician rocks found in the northern Caballo Mountains with a section in the Franklin Mountains.

MEASURED SECTION OF BLISS SS., EL PASO LS. AND MONTOYA LS., FRANKLIN MTS.

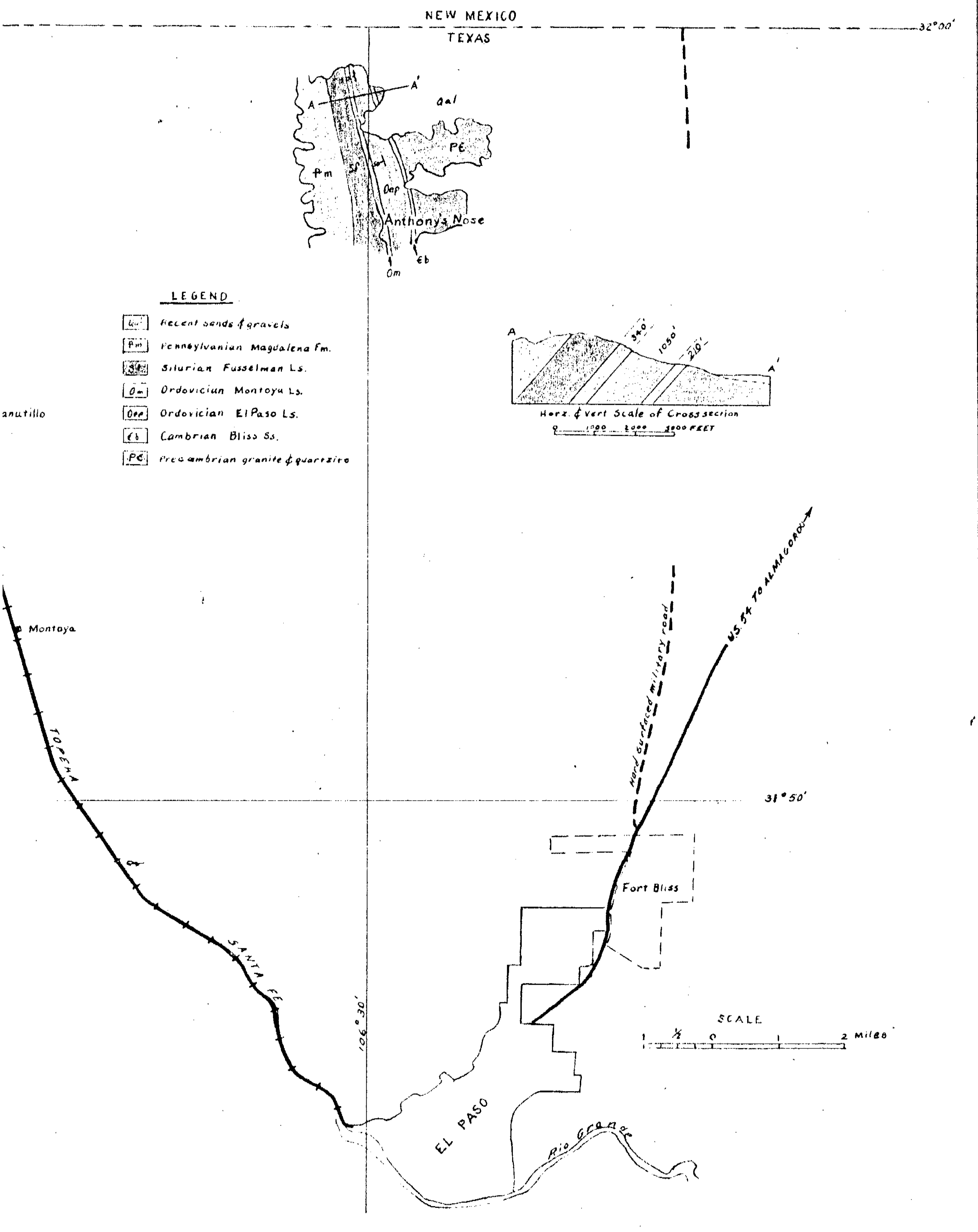


PLATE 4

SEDIMENTARY ROCKS.

Cambrian System.

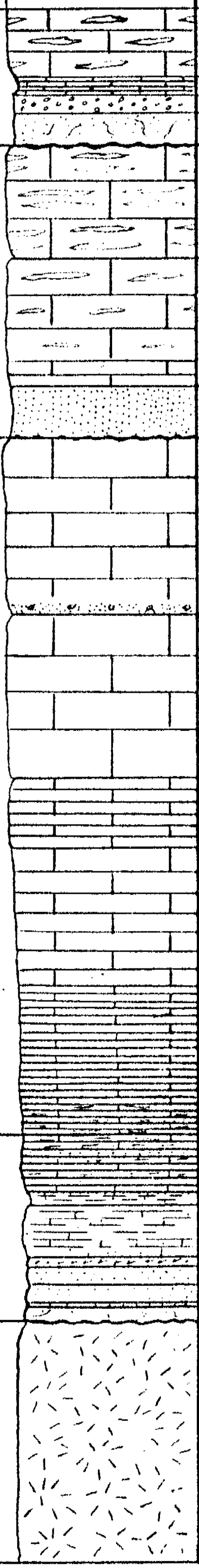
Bliss Sandstone.

The Bliss sandstone was named by Richardson (1904, p. 27) for the type section near Fort Bliss in the Franklin Mountains, north of El Paso, Texas. The name "Shandon quartzite" was originally used for this formation in the Caballo Mountains by Gordon (1907, pp. 91-92) from the mining camp of Shandon, which was located near Caballo Dam. The name had only local application and is no longer used.

Sections measured along the west flank of the Caballo Mountains and on the fault blocks northeast of Palomas Gap have thicknesses of between 100 and 106 feet. The formation is of quite uniform thickness and lithology; there are, however, many variations in the individual beds. The basal white quartzite (pl. 8, B) locally changes laterally into cross-grained sandstone or silty sandstone. Ferruginous sandstone beds grade into oolitic hematite south of the mapped area. Many thin calcareous shales in the upper part of the Bliss pinch out where a thickening of adjacent sandy limestones occurs.

The dark-colored sandstones, limestones, and shales form a distinctive color break with the underlying red granite of the Precambrian. The writer collected the following fossils that date this formation as Upper Cambrian (Shimer and Shrock, 1944, pp. 65, 285, 295):

COMPOSITE STRATIGRAPHIC SECTION OF LOWER PALEOZOIC ROCKS
CABALLO MOUNTAINS



FORM.	THICK.	LITHOLOGY	PALEONTOLOGY
MAGDALENA FORM.		Ls. dk.gry., weath lt. gry. fine xtal. w/dk.gry. cht. nod. & layers, massive	*Spirifer* sp. Horn corals & crinoid stems
	10	Ls., med.gry., fine xtal., nodular, small amt sh. Foss. thin bdd.	*Spirifer opimus* *Spirifer keokuk* *Dictyoclostus americanus* *Linoproductus* sp.
	8	Cong., lt.gry. w/pebbles of lt. & dk. gry cht.	
	18	Qtzt. wht. to brn., massive	
MONTOYA LS.	65	Ls. same as below but Foss. & 15 to 40% cht.	*Zygospira resupinata* *Resserella meeki*
	75	Ls., med.gry., coarse xtal. highly Magnesian 5% cht. nod. & layers, lt. brn. silic. stain on weath. sur.	
	30	Ss., lt.brn., med & coarse grd., sub ang to rnd. calc., weath. to dk. brn.	
EL PASO LIMESTONE	100	Ls., med.gry., fine xtal. massive, high Mg. thin ss. and cht. cong. at base	
	95	Ls., lt gray, fine xtal., Massive, slight Mg. Weathers to lt. brn	
	40	Ls., lt.gry., crypto xtal., thin to med. bdd. lt. brn. silic. stain on weath. sur.	
	146	Ls., lt.gry., fine to med. xtal thin to thick bdd. dk brn. silic. stain on weath. sur., glauconitic & shy at base	*Aphetoceras farnsworthi*
BLISS SS.	32	Ls., SS. & Sh. int. bdd., gry. grn & brn., thin to med. bdd. grades into El Paso; all are glauconitic	*Dictyonema minnesotense*, *Apheoorthis lineocosta*
		Sh., dk. red & grn., calc, sandy, w/qtzt., brn. at top	
	10	Ls., coarsly-xtall., gry & grn, sandy & cherty glauconitic & ferruginous	
	30	Olivine basalt sill	
		Ss. brn & red, coarse to med. grd. ferruginous	
	5	Ss. brn & red, fin. grd., thin bdd., ferruginous & foss.	*Lingulella* sp.
	11	Ss. yel & brn., shaly	
	8	Qtzt. wht & brn. thick bdd.	
		Granite mostly w/other igneous and metamorphic rocks	

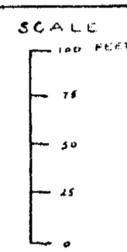


PLATE 5

J.C. Doyle

Dictyonema minnesotense - Upper Cambrian (Lower Arbuckle of Oklahoma)

Apheoorthis lineocosta - Upper Cambrian (Upper Cambrian of Colorado)

Lingulella sp. - Cambrian

rdovician System.

l Paso Limestone.

The El Paso limestone conformably overlies the Bliss sandstone and nderlies the Montoya limestone. It was named by Richardson (1904, p. 24) or exposures in the Franklin Mountains north of El Paso, Texas, where it ttains a thickness of 1,000 feet and consists almost entirely of dolomitic imestone.

The El Paso limestone outcrops west of the range where it forms the ower part of a cliff that extends from the southern boundary of the area o about one mile south of Palomas Gap, and on a steep slope north of 'alomas Gap to the point where it is faulted off northwest of Turtle Peak. t also outcrops along the lower-lying fault blocks north and west of 'alomas Gap.

In the Caballo Mountains, the El Paso limestone has been separated nto two members. Kelley 2/ has designated the El Paso limestone as a group nd divided it into the lower Sierrite formation and upper Bat Cave formation, hich correspond to the unnamed members described in this paper.

/ Dr. Vincent C. Kelley, University of New Mexico, Unpublished report.

A lower member, 300 feet thick, is conformable with the underlying Bliss sandstone. It is glauconitic and shaly at the base with alternating thick and thin beds of light-gray limestone, characterized by a dark-brown siliceous stain on the weathered surface. More massive limestone, darker gray on fresh surface and with a lighter brown siliceous stain on weathered surface, forms the top of the lower unit.

The upper member consists of 100 feet of medium-gray magnesian limestone, containing a few thin beds of coarse-grained calcareous sandstone and a thin bed of pebble conglomerate with subangular to round pebbles of dark chert at its base.

The El Paso limestone of the type section was deposited during the Canadian epoch. The lower beds of the El Paso in this area are distinctive and identical in appearance to the lower beds of the El Paso in the type section in the Franklin Mountains. Aphetoceras farnsworthi, a lower Ordovician (Beekmantown) index fossil, was found 50 feet above the base (near the Forty-one mine), substantiating the age determination.

Montoya Limestone.

The Montoya limestone was named by Richardson (1908, pp. 476-479) for Montoya Station on the Atchison, Topeka and Santa Fe Railway Company, 10 miles north of El Paso, Texas. In the Caballo Mountains, beds assigned to the Montoya limestone form the upper part of a massive cliff along the west side of the range and on the fault blocks northwest of Palomas Gap.

A lower sandstone and an upper magnesian limestone comprise the

Montoya formation in the mapped area, and correspond to Kelley's[3/] lower Cable Canyon sandstone and upper Jornada limestone of formational rank. The sandstone is light brown to white, coarse-grained, calcareous, and is 30 feet thick. It weathers to a dark brown and forms a sharp color break with the overlying and underlying magnesian limestones.

The upper magnesian limestone is medium to dark gray, weathering to a light brown. The lower 75 feet is finely to coarsely crystalline with a few scattered layers and nodules of dark chert. The upper 65 feet is finely crystalline to cryptocrystalline, fossiliferous, and contains 15 to 40 percent of dark chert, giving the rock a striped appearance.

Two upper Ordovician (Richmond) fossils were identified from the top of the fossiliferous upper member:

Zygospira resupinata (Wang, 1949, p. 18)

Resserella meeki (Shimer and Shrock, 1944, p. 353)

Richardson (1908, pp. 476-479) collected a Richmond fauna in the type section of the Montoya limestone in the Franklin Mountains. These fossils suggest that deposition took place in the Cincinnatian epoch and that the disconformity that exists between the El Paso and the Montoya formations represents a hiatus of Chazyan and Mohawkian time, and possibly early Cincinnatian time.

The Montoya limestone is overlain by Pennsylvanian rocks, and the Silurian and Devonian formations, present in the southern part of the range[3/], were not found anywhere in the northern Caballo Mountains area.

[3/] Dr. Vincent C. Kelley, University of New Mexico, Unpublished report.

Pennsylvanian System.

Magdalena Limestone.

The Magdalena limestone was named by Gordon (1907, pp. 807-816) for the Pennsylvanian section exposed in the Magdalena Mountains of west central New Mexico. Gordon considered the Magdalena limestone as a group and broke it down into two formations: the lower Sandia which consisted mostly of shale, and the upper Madera which consisted mostly of limestone. Thompson (1942, 1948, pp. 1-184) in his studies of fusilinids, recognized four faunal zones which he designated "series" in descending order, Virgil, Missouri, Deines, and Derry. The Derry series is more widely known as the Atoka, its faunal equivalent in the Mid-Continent region. Moore and Thompson (1949, pp. 275-302) recently proposed a regrouping of the Pennsylvanian system and period into three faunal zones which he called "series" and which he implied have time significance. He reduced the former series to stages (ages). Figure 1, page 16, gives a table of the various classifications used for the Pennsylvanian system.

For the purpose of this report, the writer has divided the Magdalena limestone of formational rank into two members (the equivalent of Gordon's formations) - the Sandia and the Madera - and correlated these two members with Thompson's faunal zones which were used by Cheetham [4] in his study of the fossils collected when he measured a part of the Pennsylvanian section with the writer in 1950. (See pl. 6.)

[4] Alan H. Cheetham, Unpublished research paper, NMSM, 1950.

Moore and Thompson 1949	New Mexico Bureau of Mines and Mineral Resources	Names Commonly Used in Texas	Formational Rank in Caballo Mt	
Kawvian Series (Epoch)				
Virgillian Stage (Age)	Virgil series	Cisco series	Madera member	Magdalena
Missourian Stage	Missouri series	Canyon series		
Oklan Series				
Desmoinesian Stage	Des Moines series	Strawn series		formation
Atokan Stage	Atoka series	Bend series	Sandia member	
Ardian Series		Absent in Central Texas	Absent in Caballo Mountains	
Morrowan Stage	Morrow series			
Springeran Stage	Absent			

Figure 1. Classification of Pennsylvanian Series.

The Sandia member has at its base a coarse-grained white sandstone that lies disconformably on the Montoya limestone. This sandstone locally grades into a white quartzite and is overlain by two thick beds of pebble conglomerate composed of angular to round pebbles of light-and dark-gray chert, ranging in size from 2 mm to 25 mm. Overlying the pebble conglomerate are 65 feet of thin, nodular and thick cherty limestones and 80 feet of black, green, yellow, and red shales interbedded with a few thin limestones, for a total thickness of 170 feet. The Madera member consists of 805 feet of thin-bedded to massive limestone with some interbedded shale and a few sandstones. (See pl. 8, D.)

The Sandia member forms a slope on the west side of the range between the cliff-forming Ordovician strata (pl. 8, A) and the overlying Madera member. The massive, thick-bedded limestones of the Madera member form the crest (pl. 8, A) and east flank of the Caballo Range. Both members outcrop in the fault blocks northwest of Palomas Gap. The basal quartzite and sandstone are distinctive enough in color to enable one to pick the base of the Pennsylvanian in any part of the area.

The following fossils, Spirifer opimus (lower Magdalena near Taos, New Mexico), Spirifer keokuk (?) (lower Magdalena, Socorro Mountain) and Dictyoclostus americanus (lower Magdalena, Socorro Mountain) were collected from the thin nodular limestones overlying the basal siliceous beds. This leaves no doubt that the Pennsylvanian rests directly on the Ordovician and that the Silurian and Devonian rocks found in the southern part of the range are absent in the northern Caballo Mountains area; and further, that Mississippian strata found in adjacent ranges in southern and central New Mexico are also absent.

Permian System.

The Permian system in the northern Caballo Mountains area is represented by the Abo sandstone, and by the Chupadera group which is here not divided into the Yeso, the Glorieta and the San Andres formations. Figure 2, page 19 shows the type of deposition and correlates the Permian formations of the Caballo Mountains with the Marathon and the Midland basins in West Texas.

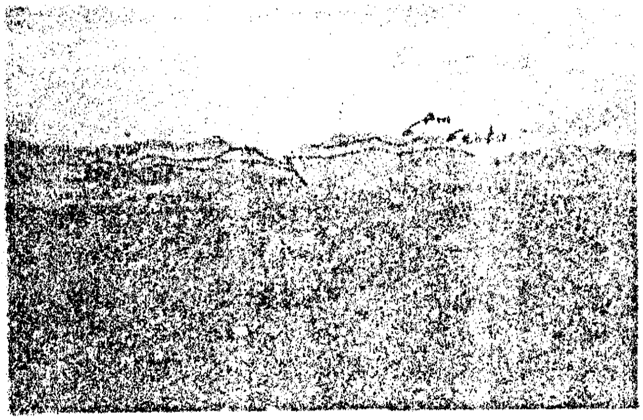
Abo Sandstone.

The Abo formation, so named by Lee (1909, p. 12) from the type section in Abo Canyon in central New Mexico, consists of interbedded brown and dark-red sandstone and shale members. Current ripple marks, lensing, cross-bedding, and the prints of land plants suggest an entirely continental origin.

The rocks of the formation are thick-, medium-, and thin-bedded, dark-red to brown micaceous and silty sandstones which are generally separated by thin-bedded, dark-red mudstones, claystones and shales. (See pl. 8, C.) A few widely separated conglomerates and limestones make up a small percentage of the formation. The mudstones show low resistance to erosion which results in the formation of hogbacks and cuestas of the more highly resistant sandstones and conglomerates. The sandstones are fine-

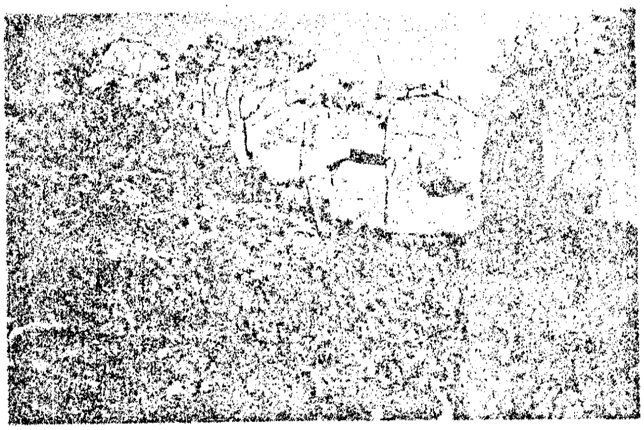
Series	ental	Lagoonal	Reef	Pontic	Pontic	Reef	Lagoonal	
OCHOA	Dewey Lake Red Beds				Dewey Lake Red Beds			Dewey Lake Red Beds
		Rustler Salado			Rustler Salado } Tessey			
				Castile	Castile			
GUADALUPE		Tansill Yates Seven Rivers Queen Grayburg	Capitan } Carlsbad	Bell Canyon	Altuda	Capitan	Gillian	Whitehorse Group
		San Andres } Chupadera	Goat Seep	Cherry Canyon	Upper Word	Vidrio		Blaine
				Brushy Canyon	Lower Word			
	Glorieta	Glorieta			Basal Conglomerate of Word			San Angelo
LEONARD	Yeso	Yeso						
	Abo		Victorio Peak	Bone Spring	Leonard	Hess		(Clear Fork (Wichita
WOLFCAMP				Hueco Powwow	Wolfcamp			Wolfcamp
		Bursum		Unnamed Limestone				

Figure 2. Correlations of the Permian system in the Southwest, based on work done by E. Russell Lloyd, Consulting Geologist, Midland, Texas, 1949.



A. Western side of range from west side of Caballo Reservoir.

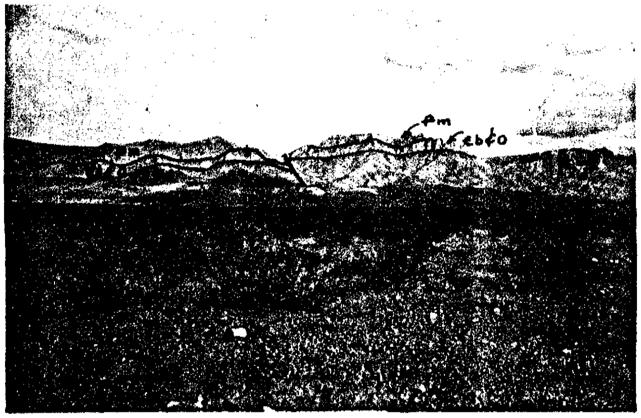
B. Contact between Precambrian granite and Bliss sandstone.

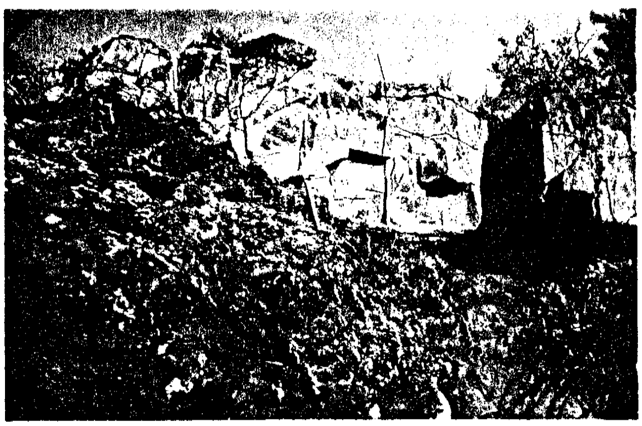


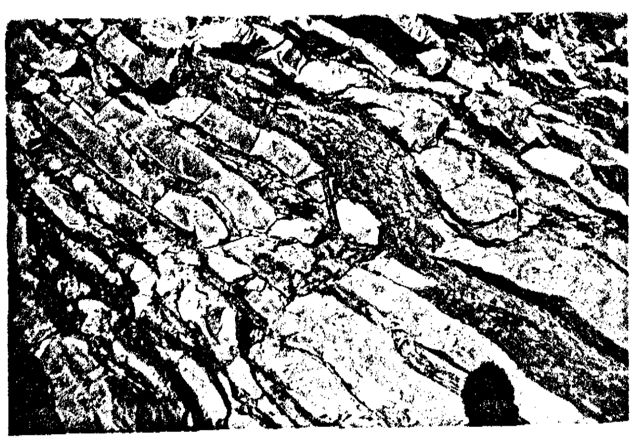
C. Shale and sandstone of the Abo.

D. Interbedded shale and limestone of the Magdalena formation.

Plate 8.


Pm
Ebto





to medium-grained, and many of the beds are crisscrossed with veins of calcite. The cementing material is iron oxide. The dark-red color of the sandstones and mudstones would seem to indicate a high percentage of iron oxide, but apparently this is not the case as the scratched or crushed surface is white, suggesting that the color is due to a thin covering of iron oxide over grains of quartz. Circular, greenish-gray spots, which vary from a fraction of an inch to one foot in diameter, are characteristic of many of the red mudstones and appear to be the result of reduction of the ferric oxide by organic material. The total thickness of the section is 1,015 feet.

The Abo sandstone outcrops along the eastern base of the Caballo Range where it lies disconformably on the Pennsylvanian limestone. Conglomeratic beds at the base of the Abo formation, exposed two and one-half miles north of Turtle Peak at the northern end of the range, contain pebbles of the underlying Magdalena limestone.

No fossils were found in the Abo beds with the exception of unidentifiable prints of plant fragments; however, figure 2, page 19 shows the correlation with rocks of known age based on lithology and stratigraphy.

Transition Facies.

A poorly exposed section of rocks, 180 feet thick, appears to be transitional from the continental deposition of the Abo red beds to the marine deposition of the Chupadera limestones, sandstones and evaporites. Land plant casts and asymmetrical ripple marks suggest a terrestrial origin.

However, salt casts in some of the younger beds conflict with this suggestion and indicate inundation and subsequent evaporation of saline waters of a shallow arm of the Permian Sea. The entire section consists of alternating shales, siltstones, and mudstones, in colors of red, brown, yellow and green.

The Abo-Chupadera contact has been mapped as the center line of the transition facies.

Chupadera Formation.

The name "Chupadera" was adopted by the U. S. Geological Survey after Darton (1922, pp. 176-182). Darton's plan was to combine the Yeso and the San Andres formations because of difficulty in separating the two formations from place to place. The original name was applied to 1,500 feet of sandstone, gypsum, and limestone capping Chupadera Mesa, the northern boundary of Jornada del Muerto, in Socorro County, New Mexico.

The Chupadera formation outcrops in a wedge-shaped area east of the Caballo Range. In the northern part the beds are steeply dipping or vertical, and the entire formation is exposed; whereas, in the central and southern part the beds dip eastward at a more gentle angle (average of 25°) and the section is partly obscured by recent silt and gravels.

In the Caballo Mountains area, the base of the Chupadera formation was placed at the base of the limestones which lie conformably on the yellow and green mudstones of the transition facies. The formation consists mostly of limestone with smaller amounts of sandstone and gypsum, and has a total thickness of 645 feet. The limestones are finely crystalline to cryptocrystalline, mostly dark gray, thin- to thick-bedded, with a fetid odor on the broken surface. The sandstones are medium-grained, yellow and red, friable and gypsiferous.

Many of the limestone beds are fossiliferous, but most of the specimens are fragmentary or weathered to a degree that makes identification difficult; however, Aulosteges medlicalliamis (Leonard age) and Euphimites sp. were found near the base, and Murchisonia gouldii and Dictyoclostus bassi (Guadalupian age) were found 150 feet below the top. Therefore the Chupadera formation here ranges from sometime in Leonardian time to sometime in Guadalupian time, if these fossils have their expected range and are correctly identified. The Chupadera formation has formational instead of group status in this paper because the Yeso, the Glorieta and the San Andres members are too poorly exposed in the area to constitute reasonably mappable units, especially considering the gradational nature of the contacts. It is easy to pick arbitrary points where the thicknesses of these members can be measured, but such points cannot even be mapped as approximate contacts. On the basis of such measurement, the members are assigned the following thicknesses:

San Andres	280 feet
Glorieta	60 feet
Yeso	440 feet

Cretaceous System.

A series of sandstones and shales 3,800 feet thick, disconformably overlying the Chupadera formation (pl. 9, A) represents the Upper Cretaceous system. Dakota sandstone, Mancos shale, and Mesaverde rocks have been recognized and mapped. Plate 18 (in pocket) shows the correlation of the Cretaceous formations in the northern Caballo Mountains, with the Cretaceous in other parts of New Mexico.

Dakota Sandstone.

The Dakota sandstone was named by Meek and Hayden (1862, p. 419) for an extensive outcrop of white, yellow, brown, and red sandstones in Dakota County, Nebraska. The Dakota was studied and mapped by Darton (1928) in sections throughout New Mexico.

A continuous outcrop of Dakota sandstone extends from the Rio Grande between Truth or Consequences and Elephant Butte Dam to a point four miles south of Palomas Gap. A few small outcrops occur south of the main outcrop.

In the Caballo Mountains, the Dakota consists of 160 feet of massive, fine- to coarse-grained, crossbedded, brown sandstone that is conglomeratic at the base and is interbedded with shale and siltstone at the top.

Although no fossils were found in the Dakota sandstone, the section exposed in the Caballo Mountains area is similar lithologically to the Dakota outcrop in the San Juan Basin where it is known to be

Upper Cretaceous, and it is also conformable with the overlying formations from which Upper Cretaceous fossils have been collected.

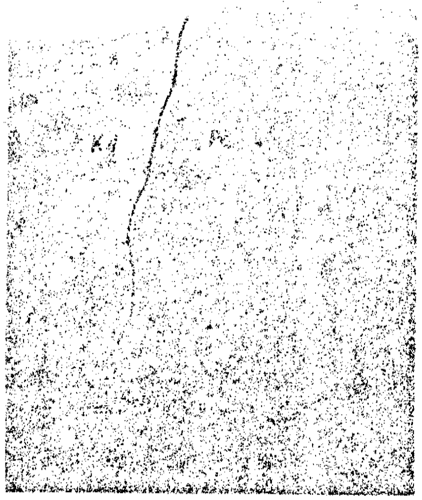
Mancos Shale.

The Mancos formation was named for thick exposures of shale in the Mancos Valley and around the town of Mancos near Mesa Verde National Park in southwestern Colorado (Cross, 1899). The Mancos shale of southwestern Colorado and northwestern New Mexico yields a Coloradan fauna (Reeside, 1924, p. 10).

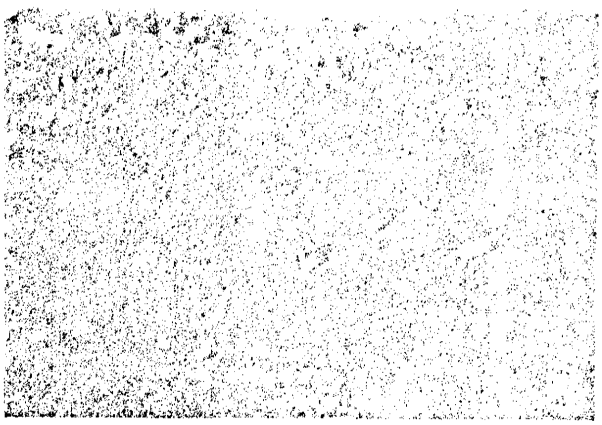
The Mancos extends from the Rio Grande in the north central part of the area to a point four miles east of Palomas Gap. The soft shale has been eroded to form a shallow valley (pl. 9, C) the entire length of the outcrop, with exposures only near the base and the top.

The Mancos exposed near the mouth of Mescal Canyon appears to be made up almost entirely of soft, dark-gray to black carbonaceous shale, varied by a few scattered, thin beds of shaly limestone and siltstone near the base and the top (pl. 9, B). A section measured near the mouth of Mescal Canyon was 265 feet thick. Throughout the length of the outcrop the Mancos is partially obscured by alluvium and gravel which cover any break in the carbonaceous shale, if any exists, that might be used to serve as a guide in subdivision and better correlation.

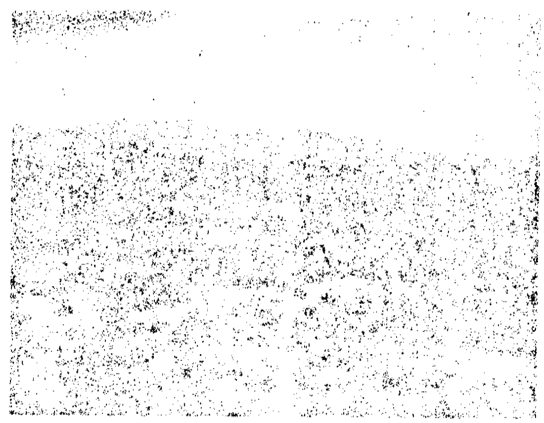
A few pelecypod fragments found in one of the upper impure limestones were a Cretaceous type but could not be identified more closely.



A. Contact between Chupadera formation and Dakota sandstone.



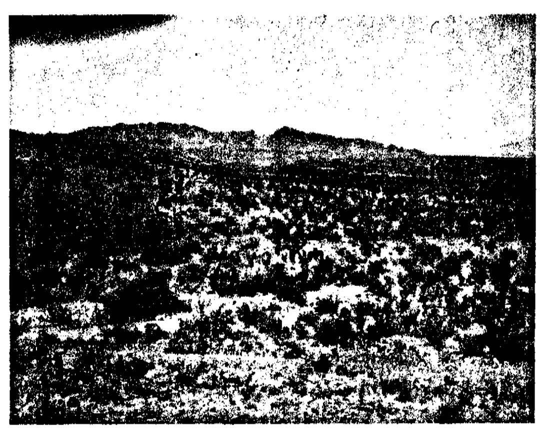
. Mancos shale with a few thin beds of siltstone and shaly limestone.



C. Flat valley, topographic expression of the Mancos shale.

Plate 9.


Kd



Lithologically and stratigraphically this section of shale is the Mancos formation.

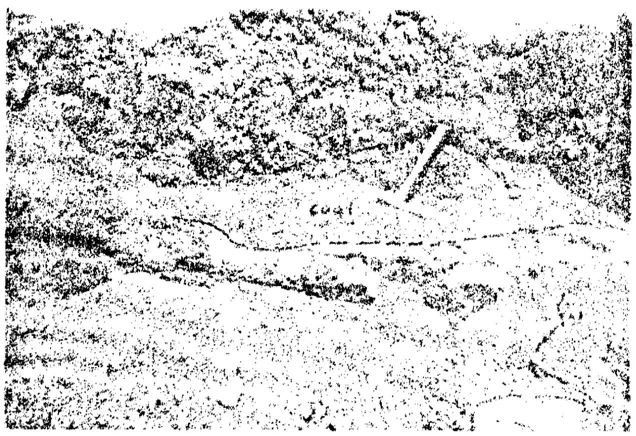
Mesaverde Formation.

The Mesaverde formation was originally designated as a group by Holmes (1877, pp. 245, 248) who divided it into three unnamed formations that are exposed on Mesa Verde in southwestern Colorado. Cross and Spencer (1899) dated the Mesaverde formation as Montanan, based on fossil specimens that were similar to those found in the Pierre shale in eastern Montana, Wyoming, and Colorado. A. J. Collier (1919, P. 296) replaced Holmes' descriptive terms with the following geographic names (descending): Cliff House sandstone, Menefee formation, and Point Lookout sandstone, derived from localities on or near Mesa Verde. J. B. Reeside (1924, pp. 13-16) has done extensive work in correlating the Mesaverde formations in the western interior regions and he concludes that the subdivisions of the Mesaverde, with reference to a chronological plane, change their positions in the stratigraphic column from place to place. W. S. Pike, Jr., in his Geological Society of America Memoir 24, correlated various sections of the Mesaverde formation in New Mexico (1947).

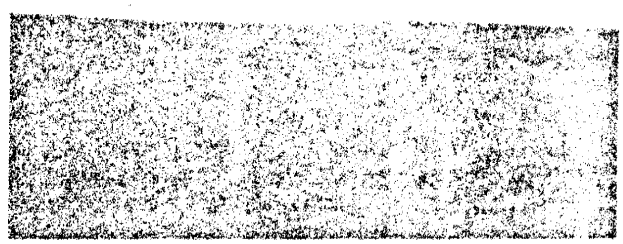
Outcrops of the Mesaverde formation occur in the eastern and northeastern part of the area (pl. 10, D). The essentially eastward-dipping interbedded shales, siltstones, and sandstones form a series of cuestas and ridges, the result of subsequent intermittent stream action. The exposures are continuous in the northeastern part of the area but occur as

A. Contact between Mancos shale and Mesaverde formation.

B. Interbedded shale, siltstone and sandstone in middle member of the Mesaverde formation.



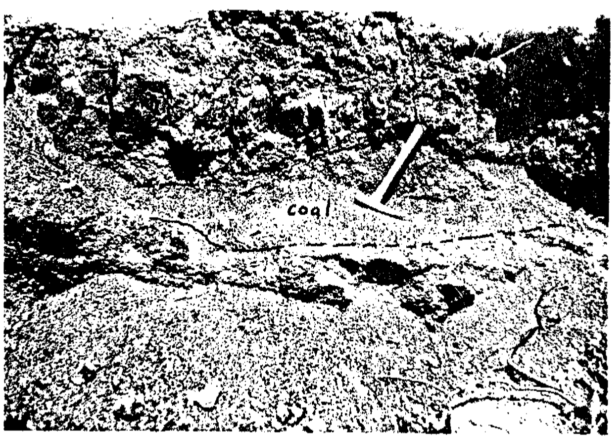
C. Coal seam in middle member of the Mesaverde formation.



D. Gently dipping beds of Mesaverde in the eastern part of the area.

Plate 10.


Km


coal

islands surrounded by the bolson plain along the eastern boundary toward the south.

The writer has subdivided the 3,375 feet of Mesaverde section in the Caballo Mountains area into three members as a means of more accurately mapping the thick section which covers over one-third of the entire area.

The lower member which is conformable with the underlying Mancos shale (pl. 10, A) consists of 1,275 feet of interbedded, gray and green, glauconitic and carbonaceous shales, mudstones, and siltstones, gray, green, red and brown, fine- to medium-grained, thin-bedded to massive sandstones, and a few narrow seams of coal. The sandstones are predominant in the lower part of the member, and the shales, mudstones and siltstones are predominant in the upper part of the member. The top of the lower member has been placed at a bed of gray sandstone that weathers chocolate brown and contains many fragments of an unidentified Ostrea type pelecypod. This bed can be traced the length of the main outcrop in the northeastern part of the area and has been recognized in some of the isolated outcrops along the eastern boundary. The shell fragments make up over 50 percent of the bed in parts of the area, and in other places, where the rock has been eroded, they form a dark band where they lie scattered on the ground.

The middle member is similar to the lower member in composition, (pl. 10, B) but in addition it contains many more narrow seams and pods of coal in some of the lower shale beds (pl. 10, C). The upper part of the middle member is predominantly sandstone and the lower part that contains the coal seams is mostly shale and siltstone. The coal is a very poor grade and is exposed at several points where it grades in and out of carbonaceous shale. The entire middle member is 1,650 feet thick.

The base of the upper member is placed at the bottom of a thick section of thick-bedded to massive, cross-bedded, fine- to coarse-grained cream and brown sandstone about 175 feet thick, which grades upward into silty sandstone and shale for a total thickness of 450 feet.

No attempt was made to make a faunal collection from the Mesaverde; however, Inoceramus barabina and Ostrea glabra (?) were found near the base of the lower member which indicates Montanan age.

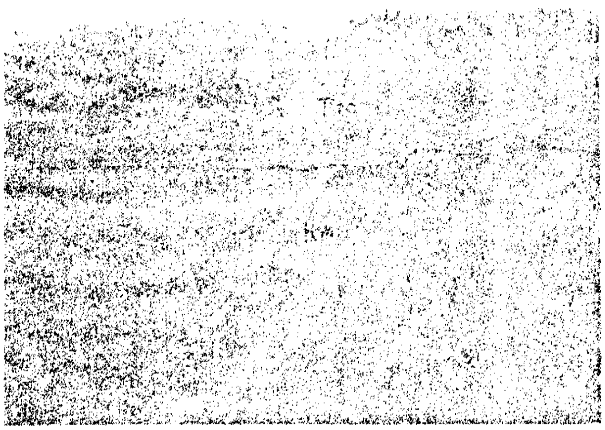
Tertiary-Quaternary System.

T C Formation.

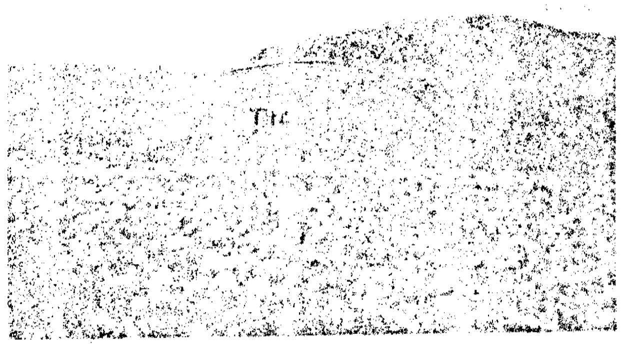
A section of reworked, partially consolidated sands, gravels, and conglomerate, in angular unconformity with the Cretaceous rocks (pl. 11, C) in the stream beds in the northeastern part of the area and lapping against or overlying the Precambrian (pl. 11, A, B, and D) and early Paleozoic rocks in the western part of the area, has been arbitrarily named the T C (Truth or Consequences) formation, after the town of that name. The upper part of the T C formation, which consists of partly consolidated sands and gravels, is lithologically similar to the type section of the Santa Fe formation along U. S. Route 85 in the vicinity of Santa Fe, described by

A. T C formation in the northwestern part of area.

B. T C formation overlying Precambrian granite.

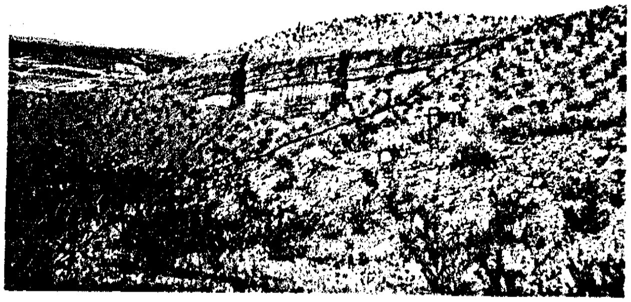


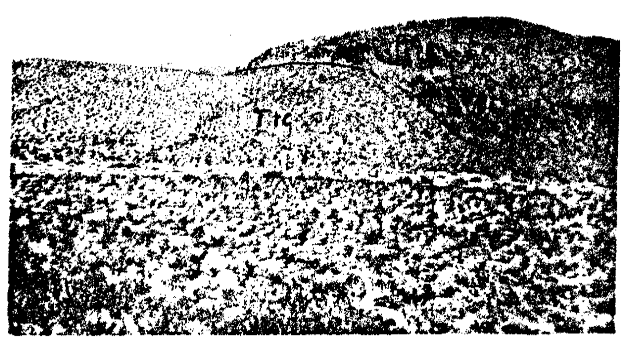
C. T C formation in angular unconformity with Mancos shale.



D. T C formation lapped up against fault scarp of Precambrian granite.

Plate 11.





Hayden (1869, pp. 66, 90). It might be better to correlate the lower part of this formation with the Gila conglomerate described by Gilbert (1875, pp. 540-541) and found in southwestern New Mexico in the Gila, San Francisco, Bonita, and other creek and river valleys. Gilbert describes the formation as a "system of valley beds of which conglomerate is the characteristic member" and "the boulders of the conglomerate are of local origin; the cement is calcite." The formation on the west side of the Caballo Mountains is soft conglomerate in the younger beds but becomes very hard and compacted in the lower part of the formation. The boulders and pebbles are all local and consist mostly of Precambrian granite and early Paleozoic sediments which are cemented together by calcite where the limestone has partially gone into solution. The size of the boulders and pebbles ranges from a fraction of an inch to three feet in diameter.

The T C formation along Palomas arroyo, which drains the area of Abo sandstone east of Palomas Gap in the central part of the area, and the part of the area where the formation laps up against the Abo sandstone in the northwestern corner, has a reddish color caused by sand from the Abo or ferric oxide leached from the Abo. Palomas Gap thus appears to have been a drainage channel during the deposition of the T C formation.

On the northeastern side of the range, portions of the T C formation have been covered by a basalt flow. Thin layers of older conglomerate, composed of fragments of the underlying Cretaceous rocks are exposed in several places in contact with the overlying volcanics. In other areas where the basalt has been dissected by intermittent streams, younger sandstones and conglomerates of the T C formation contain basalt pebbles and boulders and were deposited in stream beds 300 feet below the top of the basalt flow. This indicates that the T C formation of this paper includes units of widely varying ages, probably ranging from as early as Miocene to parts of Pleistocene or Recent time.

Numerous angular unconformities within the formation are probably the result of fluviatile channeling and deposition.

The thickest section of the T C formation inspected by the writer was in the Palomas arroyo, near its mouth, where an estimated 250 to 300 feet are exposed.

Quaternary System.

Definitely Quaternary sediments, excluding the upper part of the previously described T C formation, are recent silts, sands and gravels occurring as thin mantles over older rocks. However, along the Rio Grande and along the bolson in the eastern part of the area, the silt attains much greater thickness.

IGNEOUS AND METAMORPHIC ROCKS.

Precambrian System.

Very little work was done in the Precambrian rocks other than to outline the areas exposed by faulting on the west side of the range. The oldest rocks are metamorphosed schists and quartzites that were later intruded by granite and related rocks (pl. 12, A and B). An estimated 95% of the exposed Precambrian is a gray to red fine- to coarse-grained biotite granite. Associated with the granite are numerous dikes of granite gneiss and pegmatite.

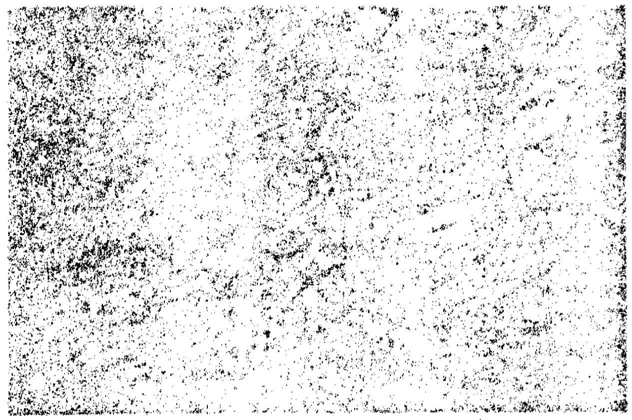
The metamorphosed sediments outcrop in various places in the western part of the area, particularly in the northern part above Palomas Gap. All exposures visited by the writer are either enclosed or cut by the granite. Pegmatite dikes are found south of Longbottom Canyon and consist of quartz, orthoclase, and muscovite. The best exposures of granite occur along the western base of the Caballo Range. In places, the granite is undergoing rapid disintegration to a coarsely granular surface deposit of arkose. This is particularly true where the exposures have been eroded to gently sloping surfaces.

The granite, metamorphic and associated rocks unconformably underlie the Cambrian Bliss sandstone. The contact indicates a long period of erosion, during which the Precambrian terrane eroded to a surface of low relief. Everywhere the writer observed the contact, the Bliss formation showed depositional relationship to the Precambrian.

Tertiary System.

Igneous representatives of the Tertiary system are dikes, with connecting sills in some instances, and a later cinder cone and lava flow of

A. Intrusion of granite in metamorphics.



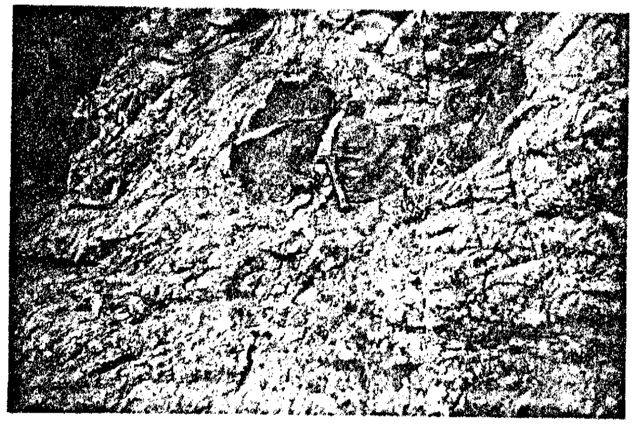
B. Xenolith of schist in granite.

C. Olivine basalt dikes cutting the Mesaverde formation.

D. Lava, ash beds and gravel.

Plate 12.


Kmcq




Tba
Kmks
Kmv
Kmx


Tbe
ash
gravel

olivine basalt (pl. 12, D). The lava flow has been separated into patches which visual continuity relates to a single flow, as distinct from others to the north.

The olivine basalt dikes (pl. 12, C) are concentrated in the northeastern part of the area and appear on the aerial photographs as a series of parallel lines trending northwest-southeast across the sediments. The dikes apparently are fill fractures due to regional extension in the earth's crust, operating along a northeast-southwest direction. They antedate the overlying lava flow as evidenced by the freshness of the lavas as compared to the high degree of weathering and uniform truncation by erosion of the dikes. They do not cut the overlying lava flow.

The olivine basalt flow originated from Caballo Cone (pl. 3, D) in the northeastern part of the area - a simple cinder cone with a breached crater. Its state of dissection is early youth as is that of the lava sheet derived from it. This is apparent, since in some parts of the area the lava overlies thin beds of ash and lapilli (pl. 12, D) which relates the flow to the contiguous cone with its volcanic bombs, lapilli, and pyroclastics. Of the once continuous sheet, only small remnants remain, overlying the horizontally beveled surface of Permian and Cretaceous sediments and locally soft sandstone and conglomerate resulting from erosion of the underlying sediments.

The eruption and subsequent lava flow cannot be dated closer than late Tertiary or Pleistocene, from the evidence available in the area.

A long period of time must have elapsed after the post-Cretaceous crustal disturbance to allow the sediments to become beveled to a nearly flat surface prior to being covered by the flow. The flows farther north, particularly at San Marcial in Socorro County, are very similar in physiographic appearance and composition, and have been dated as Quaternary by Harley (1934, p. 40); however, comparison is also possible with flows in Santa Fe County that are interbedded with Pliocene sands and gravels. The great amount of material that has been removed by erosion, leaving only remnants in the area, suggests a considerable time interval since the extrusion, but this material could have been removed in a few thousand years, given proper base level conditions. The necessary base level conditions were not produced until the relative downthrow of the Rio Grande graben. The time interval between the flow extrusion and commencement of erosion may be much longer or much shorter than the time since the erosion began.

STRUCTURE.

The structural relations in the Caballo Mountains are complicated, and to depict them completely and in detail would require a larger scale base map than was available. Many of the drag folds and minor faults have been omitted on the map. They occur in such abundance in limited areas that they detract from and confuse the regional picture; the difficulties of presentation are multiplied by the lack of topography, particularly where structural surfaces alternately parallel or cut at high angles the topographic surface.

Folding.

The Caballo Mountains have undergone intense parallel folding of all rocks from the Precambrian through the Cretaceous; later rocks (T C formation and basalt flow) have only been tilted.

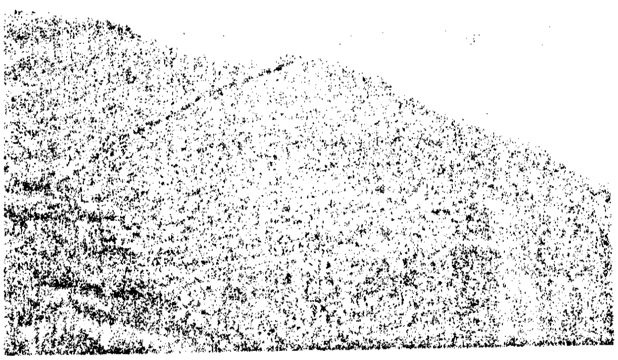
The most intense folding is along the crest and west slopes of the Caballo Mountains (pl. 13, A and B). In the vicinity of Turtle Peak where the range trends essentially north and south, the folding is roughly parallel to the crestline. On the west side of the crest, just south of Turtle Peak, erosion has exposed the beds at their point of maximum curvature. In this area the dip of the axial surfaces varies from 45° to 60° west, and the plunge is about 5° north. Farther south and to the east of Palomas Gap, these same folds have their axial surfaces dipping east (pl. 14, D). The folds north of Palomas Gap are terminated by faulting at the north end of the range and die out southward in the vicinity of Palomas Gap.

South of Palomas Gap, where the range trends slightly east of north, the folds cut the crest at a slight angle and the traces of the axial surfaces run up one side and down the other so as to divide the range into areas where the beds are overturned or steeply dipping, from areas where the beds are relatively flat lying.

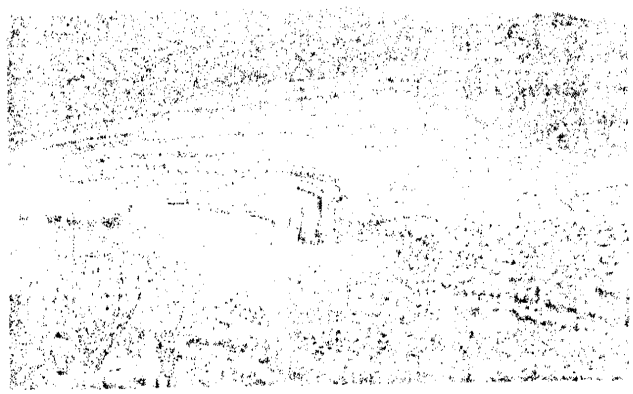
The metamorphic effect of the folding on some of the coarse-grained sandstones is interesting. In the area around Turtle Peak, sandstones of

A. Folding on Turtle Peak; dotted line represents single bed, dashed line represents axial surface.

B. Close-up of insert in A.

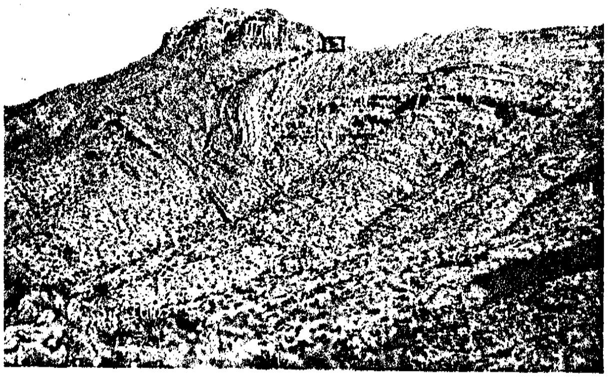
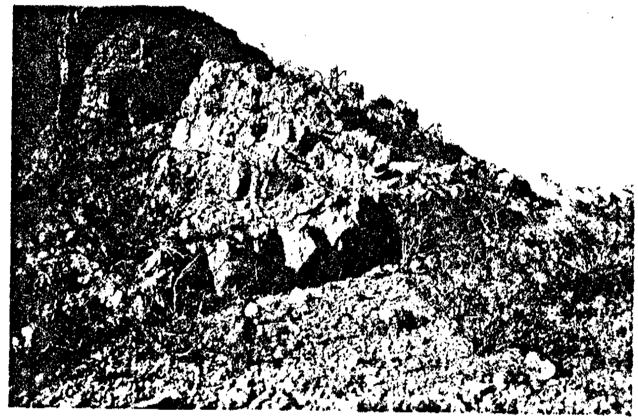
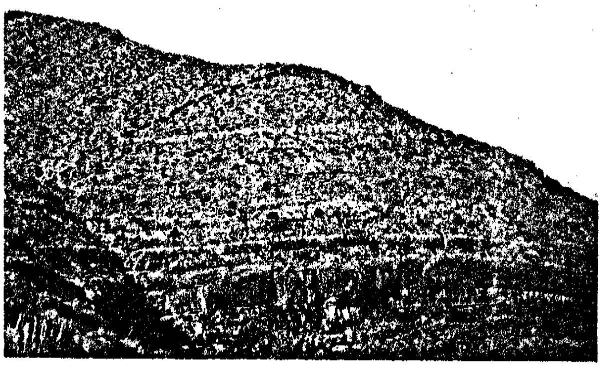
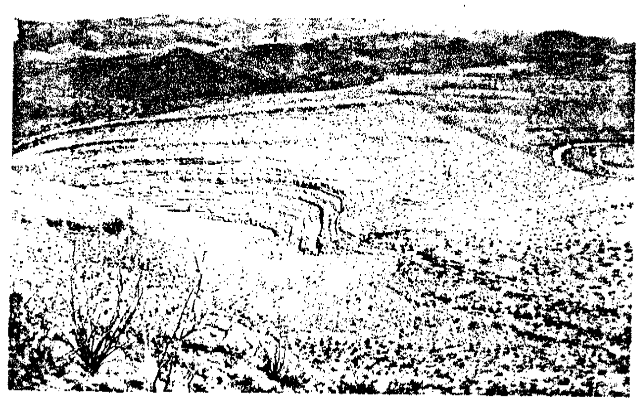


C. Syncline on east slope of range, south of Turtle Peak; dashed line represents axial surface.



D. Example of minor folding in the area.

Plate 13.

Pennsylvanian age are quartzites where they intersect the axial planes of the folds in the area. It was also noted that the early Paleozoic beds have shattered and fractured to a greater extent than the Pennsylvanian beds, where involved in folding.

The folding, or at least the initial folding, was followed by faulting as evidenced by shearing of the fold axes by faults.

Faulting.

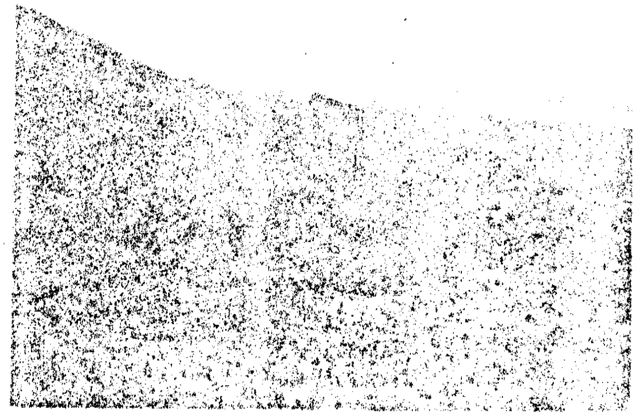
Faulting in the northern Caballo Mountains appears to be caused by the same forces that produced the folding where the stress continued to the point of rupture. Detailed information could not be determined for many of the faults because of talus cover or subsequent erosion and modification along the fault scarps.

The faulting can be classified under three groups in accordance with the general directional trend: a northwest-southeast group, a north-south group, and an east-west group.

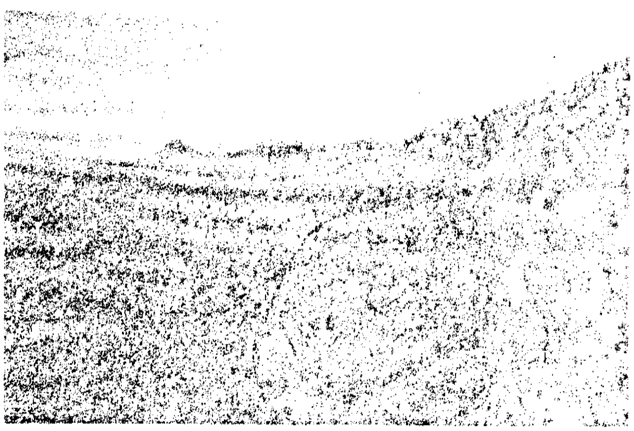
The area is most intensely faulted on the west side of the range north of Palomas Gap. The earliest faulting is represented by an échelon pattern of northwesterly trending faults that form tilted fault blocks (pl. 15, D). These were cut by later longitudinal, north-south normal faults, of which Caballo fault is a good example.

Caballo fault extends the length of the northern Caballo Mountains. It can be traced for most of its length except where the fault line is

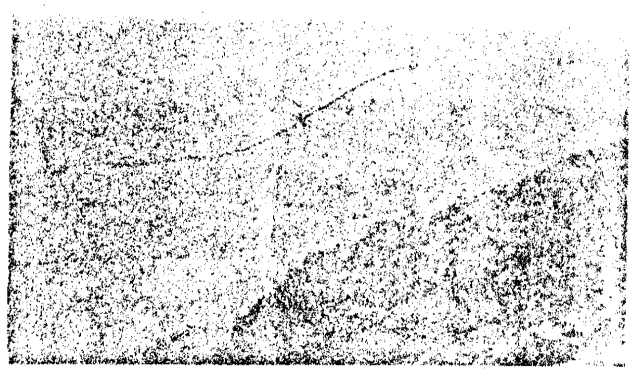
A. Universal fault and mine.



B. Imperial mine on fault near west end of Palomas Gap.

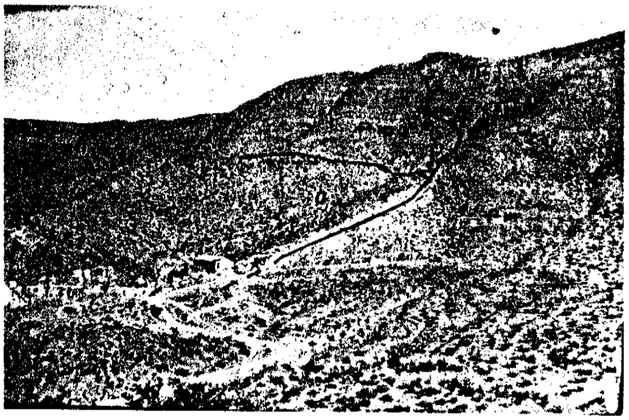


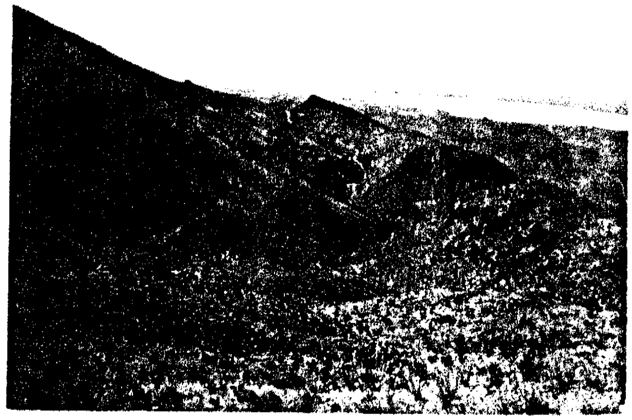
C. Transverse fault on west slope, north of Palomas Gap.



D. Synclinal valley east of Palomas Gap.

Plate 14.





locally covered with debris. Southwest of Turtle Peak, the fault plane dips 67° west and has a stratigraphic throw of about 1,200 feet.

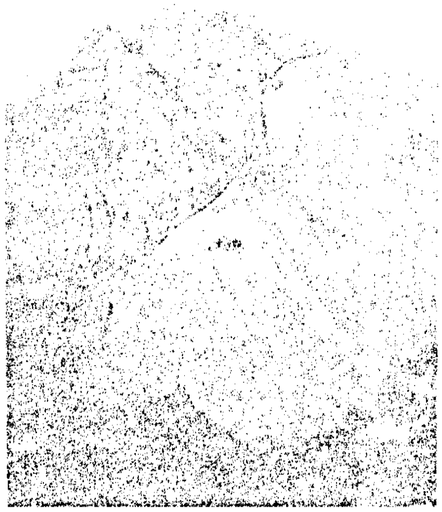
Several transverse faults lie almost normal to Caballo fault, as exemplified by the Universal, Palomas, and Longbottom faults. The Universal fault is a normal fault with a stratigraphic throw of not less than 400 feet and dips 75° south, just east of the Universal mine (pl. 14, A).

Palomas fault, however, is a transverse reverse fault, where the Bliss sandstone is in contact with the Magdalena limestone but dies out northeastward as a bedding plane fault. The stratigraphic throw is about 900 feet and the fault plane dip is 60° northwest where the Bliss is in contact with the Magdalena. (See pl. 15, A and B.)

Longbottom fault is also reverse and trends south 80° east, for over four miles, dips 85° south and has a stratigraphic throw of about 800 feet on the west slope of the range. The south side of the fault is upthrown so that the Precambrian granite is against the lower Pennsylvanian shales and limestones at the head of Longbottom Canyon.

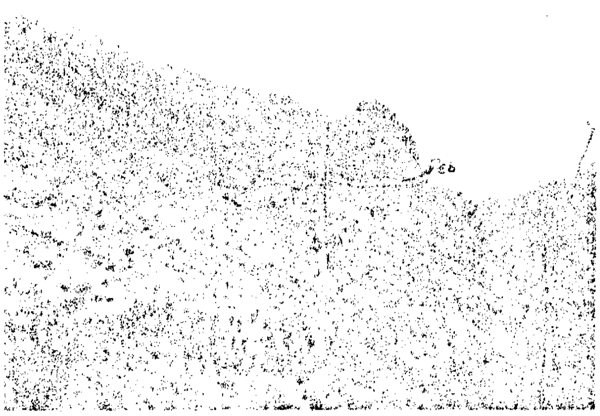
The western slope of Turtle Peak is cut by low angle (30° to 50°) faults that trend approximately north. They start close together but gradually widen out along their northern extension. The pattern is typical of slump blocks.

Many of the smaller faults in the area are transverse normal faults (pls. 14, C and 15, C) and are of economic importance where they occur in

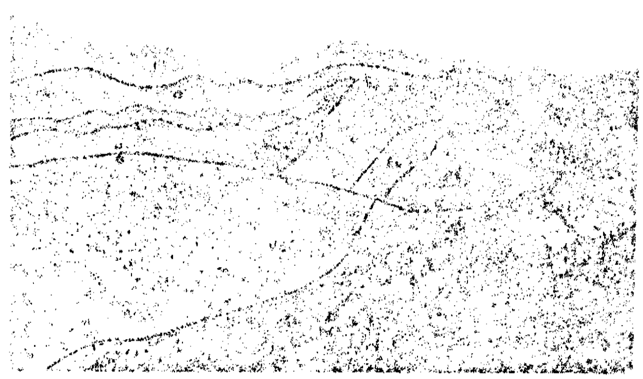


A. Palomas fault.

B. Close-up of Palomas fault showing relatively fresh surface.



C. Transverse fault one-half mile north of Palomas Gap.



D. Tilted fault blocks, south of Universal fault.

Plate 15.

fЄb

the Paleozoic formations, in that they serve as channels for mineralizing solutions.

There are several indications that faulting continued in the area up through Tertiary time. About one mile southeast of Turtle Peak, a remnant of the basalt flow dips south 65° east at an angle of 18°. Palomas fault has a relatively fresh fault surface (pl. 15, B) in Palomas Gap, suggesting later movement along the old fault line. North of Hatch, the writer observed two separate sections of partially consolidated sands and gravels, in angular unconformity to each other, both of which are comparable to the upper parts of the T C formation.

Structural Analysis.

Any analysis of the forces causing the general pattern of folds and faults is hypothetical. This is particularly true in the northern Caballo Mountains where the majority of faults do not present evidence other than their trend or relative movement.

A north-south force couple (fig. 3) is one possible explanation of the fold and fault patterns.

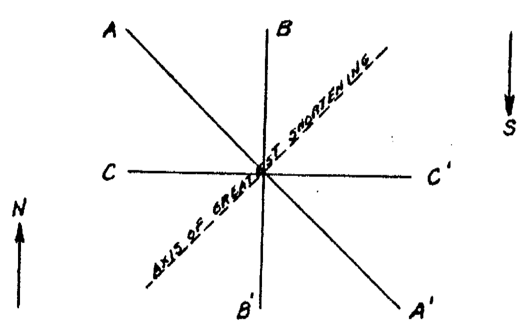


Figure 3.

In figure 3, N and S represent the hypothetical north-south force couple. A - A[1] represents the axis of folding and later rupture, normal to the direction of greatest shortening. B - B[1] and C - C[1] represent the north-south and east-west fault groups formed by shearing.

The time of deformation cannot be dated earlier than post-Mesaverdean, and indications are that movement occurred in the Quaternary period.

Geologic History

The earliest record in the area indicates deposition of Precambrian sediments which were later intruded by biotite granite and associated igneous rocks. A period of erosion followed the intrusion and the area was peneplaned.

The first evidence of marine inundation is in the Upper Cambrian when the Bliss sandstone was deposited. The hiatus that represents Chazyan, Mohawkian, and possibly parts of Upper Canadian and Lower Cincinnatian time, suggests a period in which the area remained above sea level, during which non-deposition or erosion interrupted the normal succession. The area was inundated during Montoyan time until the seas regressed to the south, as evidenced by the increase in thickness of the Lower Paleozoic sediments toward the south, particularly in the Franklin Mountains. This regression produced a hiatus representing the Silurian, Devonian and Mississippian periods. According to Dr. Vincent C. Kelley 5/ of the University of

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5/ Personal communication with Dr. Kelley, April, 1951.

New Mexico, Silurian and Devonian sediments are present south of Brushy Mountain, and probably represent the northern limit of the Silurian and Devonian seas in this immediate vicinity.

The limestones and shales with marine fauna at the base of the Pennsylvanian system indicate a return of the seas in Atokan time, and continued inundation through Desmoinesian and possibly Missourian time. At the end of the Pennsylvanian, the seas regressed and the land remained above sea level while the Abo formation was deposited.

During Aboan time the area was probably a well-drained region of very hot and very humid climate, conditions conducive to the formation of red sediments (Krynine, 1949, pp. 61-63). These conditions would also account for the stream ripple marks, cross-bedded sandstones like the channel sands of streams, and the fossils of land plants.

Seas again invaded the area in middle Permian time, depositing the Chupadera formation. The presence of evaporites is proof of very shallow seas advancing over a flat surface. Evaporation was only partial as no beds of salt were found, although a few casts of salt crystals were observed.

At the end of Chupaderan time, the Permian seas receded southeastward from the area. A hiatus from Middle Guadalupian to the beginning of Dakotan time represents a period of erosion, or at least terminating in uplift and erosion, as evidenced by the disconformable contact of the Dakota sandstone with the Chupadera formation. It is possible that rocks of Ochoan time, such as are represented by the thick beds of evaporites in Lea and Eddy counties to the east, may have been present in the area at one time. Lower Cretaceous rocks that are present to the south, particularly in Hidalgo County (Reeside, 1944), and Triassic rocks, such as the Dockum group exposed around Carthage in Socorro County, may also have overlain the area but were removed in pre-Dakotan time. The cross-laminated sandstones interbedded with carbonaceous shales, which are found throughout the Cretaceous system, suggest an alternating regression and transgression of shallow seas, bordered by swamp deposits which were repeatedly inundated during the Upper Cretaceous period.

The uplift of the land surface during Paleozoic and Mesozoic time must have been gentle and on a continental scale, unaccompanied by folding, tilting, or fracturing of the strata, because throughout the long interval of time the attitudes of beds above and below the surfaces of erosion remained the same.

Evidence in the area does not justify dating the folding closer than post-Mesaverdean; however, it is possible that it was started by the late Cretaceous and early Tertiary igneous activity which occurred around Silver City and other places in southwestern New Mexico (Harley, 1934, pp. 38, 39). As the igneous activity of the region became more extended, the initial folds continued to develop and finally resulted in faulting.

A period of erosion followed the crustal deformation of post-Mesaverdean time. The first evidence of this is the T C formation in angular unconformity on the Cretaceous and older rocks.

During the deposition of the T C formation, the area was intruded by basic dikes with a general northwest-southeast direction, which suggests that the area underwent a regional extension from a northeast-southwest direction. This would form fractures which would act as channels for the intruding magma. It is possible that these extension fractures were caused by magmatic pressure exerted along zones of weakness that were formed during the crustal deformation.

A period of volcanism followed the basic dike intrusion, during which the pediment surface in the northeastern part of the area was covered with ash beds and basalt.

Deposition of the T C formation continued into the Pleistocene, as the upper beds contain pebbles and boulders of basalt, indicating a period of erosion since the volcanism.

The Quaternary period was essentially a period of erosion during which the upper T C formation was channeled and redeposited; the basalt sheet was dissected and partially removed; the Tertiary pediment, over which the basalt flowed, was dissected by subsequent intermittent stream drainage developing headward from the Rio Grande; and the bolson silts, sands and gravels, which mantle the Cretaceous and Tertiary sediments of the Jornada del Muerto, were deposited.

ORE DEPOSITS

Fluorite is the principal ore in the northern Caballo Mountains area. Most of the deposits are on the west side of the range, occurring in fissure veins which have been formed by replacement or space-filling processes in the Precambrian granite or Paleozoic limestone and dolomite. The largest fluorite deposits occur in the Upper Ordovician rocks and die out rapidly near the Pennsylvanian contact. The fluorite is generally fine-grained and white, with small amounts of pale green and pale blue. Quartz is the predominant gangue minerals in veins in Precambrian rocks, whereas calcite is the principal gangue mineral in veins in the Paleozoic sediments. Barite is a common vein mineral in either sedimentary or igneous host rocks. Scattered crystals of galena occur in most of the deposits. All veins in the region are presumably connected to a deep-seated Tertiary intrusive similar to that which outcrops on the west face of the Fra Cristobal Range to the north and near Cutter, 13 miles east of Palomas Gap (Harley, 1934, p. 201).

The White Star, Tingley, Oakland, and Universal veins are on a group of seven patented claims which have been owned since 1924 by Blanchard Hanson of Truth or Consequences. These prospects were worked intermittently from 1926 to 1934 by Fluorspar Mines of America, Inc. The deposits were reopened in 1940 by the United States Fluorspar Company, which constructed a flotation mill nearby on the east side of the Rio Grande. Mining and milling were discontinued in 1942 because of metallurgical and

STRUCTURE MAP OF UNIVERSAL AND OAKLAND PROSPECTS

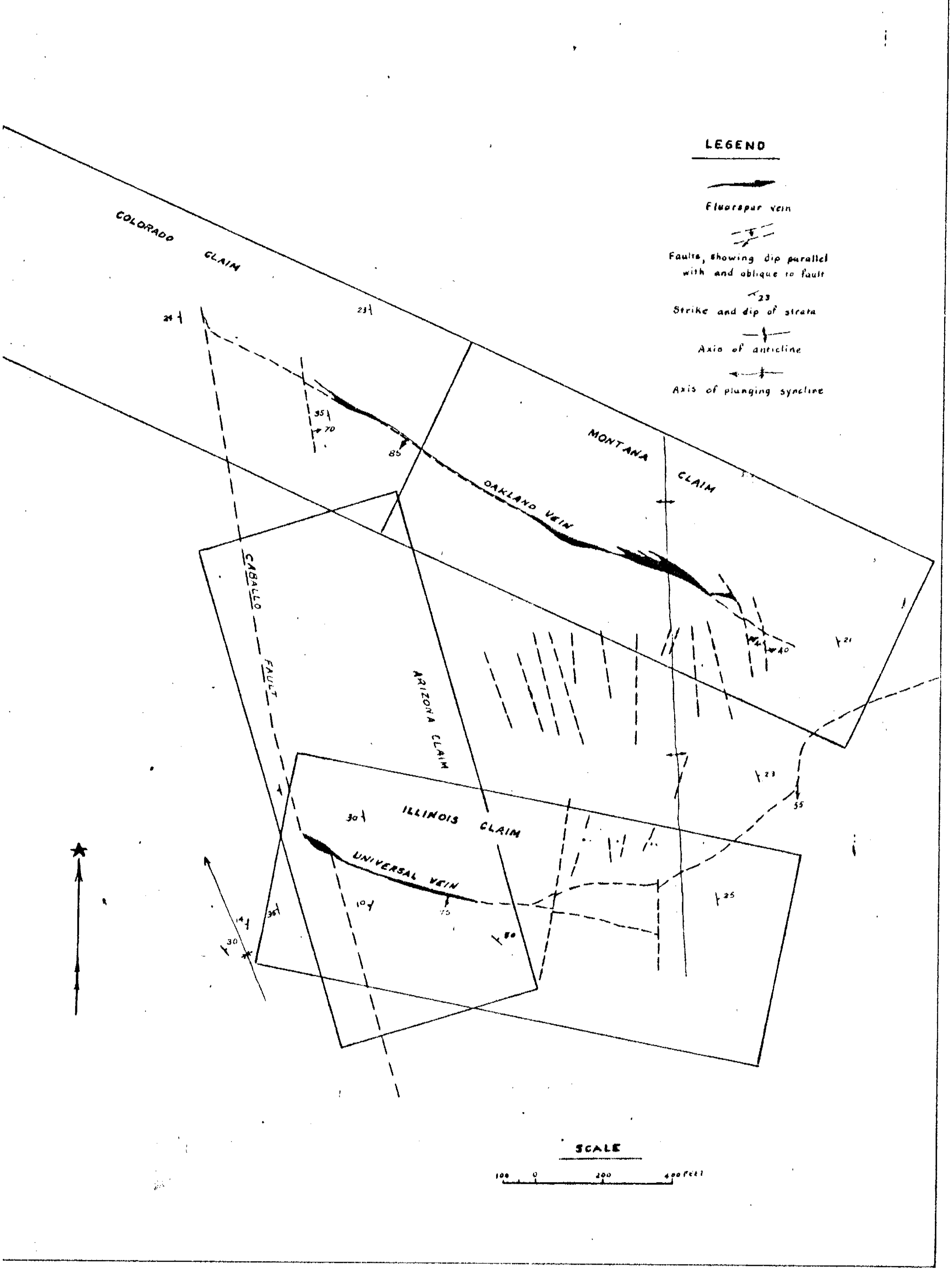

PLATE 19

transportational difficulties, in spite of urgent need for fluorspar in war industries. Preliminary examining, sampling, diamond-drilling, and analyzing were carried on by the U. S. Geological Survey, Federal Bureau of Mines, and the Humphreys Gold Corporation, from 1942 to 1944. The object of this survey was to determine whether it would be feasible to continue work with the expectation of opening up new adjacent shoots or high grade extensions of the abandoned ones. The preliminary report (Rothrock, 1945) was inconclusive and gave no information as to the future possibilities of the mines inspected in the area. The Universal mine (pl. 14, A) started up again in March, 1951. Blanchard Hanson, with a small crew, has been mining about two carloads of fluorite per day, transporting the ore by truck to Engle and thence by rail to Los Lunas, New Mexico, where it is processed by the Zuni Milling Company.

The Imperial prospect (pl. 14, B) also owned by Blanchard Hanson, lies on the south side of Palomas Gap. Small amounts of fluorspar were marketed until 1944.

The Bluejay mine on the eastern slope of Brushy Mountain is the only other mine in operation. It is owned and operated by Mike Gallegos of Hatch, New Mexico. The ore mined contains galena with subordinate amounts of chalcopyrite and fluorite. The fracture-filling mineralization is associated with the Longbottom fault. Up until April, 1951, no ore had been shipped, but a few tons were stock-piled at the mine. Gallegos intends to truck the ore to Caballo Siding and then ship by rail to

Deming, New Mexico, for processing.

The Bluejacket mine is an open cut 90 feet long, 25 feet deep at the face, and the zone is as much as 15 feet wide in places. Fluorite, quartz, and barite were deposited in the fault zone that forms the east side of the open cut. In 1941, 600 to 1,000 tons of ore were mined, and the mine shut down shortly afterwards.

The Forty-one prospect contains several sub-parallel fluorspar veins that trend north. The veins are fissure fillings in granite and are crossed by east-west trending veins that contain low-grade manganese ore.

The White Swan, Harding and Napoleon-Rosa Lee were originally worked for lead, but later (1919) vanadium was recognized in the ore. All veins are along fractures in the Madera member of the Magdalena limestone.

The Cox mine, which is essentially a fluorspar prospect, consists of several veins in the Magdalena limestone that occupy small fracture zones. A few scattered grains of galena were found in different parts of the prospect. A total of 705 tons of fluorspar was marketed during the period 1922-1944.

The Dewey mine, north of Palomas Gap on the east side of the range, was originally a small lead prospect which was purchased by the Southwestern Lead and Coal Co. in 1907. In 1909, a thin coating of brown crystals, thought to be cerussite, was determined to be vanadinite. A. B. Bement, a stockholder in the company, organized the Vanadium Mines Co.

which did extensive development work in the mine during 1910 and 1911. A few pounds of vanadium oxide were produced before it was finally shut down in 1911.

Weak copper mineralization is found in the Abo sandstone, just east of Palomas Gap. The sulfide copper minerals include chalcopyrite, chalcocite, and covellite; the oxidized minerals are malachite and azurite. The gangue minerals are predominantly calcite and barite, with minor amounts of pyrite. The mineralization is the result of replacement along fractures.

For detailed descriptions of the ore deposits of the area, the following references are suggested:

Harley, G. T., The Geology and Ore Deposits of Sierra County, New Mexico, New Mexico School of Mines, State Bureau of Mines and Mineral Resources, Bulletin No. 10: 1934.

Rothrock, H. E., Johnson, C. H., and Hahn, A. D., Fluorspar Reserves of New Mexico, New Mexico School of Mines, State Bureau of Mines and Mineral Resources, Bulletin No. 21: 1946.

Hess, F. L., Vanadium in the Sierra de los Caballos, New Mexico, United States Geological Survey Bulletin 530: 1947.

OIL POSSIBILITIES

The Pennsylvanian and Cretaceous formations contain good shallow marine shale and limestone deposits, as evidenced by crinoids, thick-shelled pelecypods, and other fossils that had a shallow marine habitat. These might well be the source beds for oil and gas. Porous sands are present, particularly in the Cretaceous, which might serve as reservoir rocks; however, no tests were run on any samples to determine their permeability.

Although much of the eastern part of the area, which is underlain by the thickest section of sediments, is partly obscured by recent deposits, the numerous isolated exposures indicate local structural highs, represented by both anticlines and domes, which are most numerous just outside the eastern boundary of the area. Faulting, which would serve to bring source beds into contact with reservoir rocks or would act as dams to trap hydrocarbons by bringing impermeable and permeable horizons into contact with one another, also occurs mostly outside the eastern boundary.

Many of the oil-producing formations in southeastern and northwestern New Mexico are the stratigraphic equivalents of the formations found in the Caballo Mountains area.

In the period from 1940 to 1948, O. R. Wofford 6/ drilled three wells

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6/ Personal communication: 1950.

in T. 14 S., R. 2 W., with the following results:

Name	Total Depth in feet	Started in	Abandoned in	Results
Wofford No. 1	207	Mesaverde	Mesaverde	Dry
Wofford No. 2	533	Mesaverde	Mesaverde	Dry
Graham State No. 1	507	Mesaverde	Mesaverde	Show of gas - 300 feet Show of oil 438 feet (Saturated sand)

Several oil companies in the past year have been working in the Jornada del Muerto, and apparently surface indications look promising enough to warrant further exploration, since three geophysical companies are currently making complete seismic surveys of the area.

The eastern part of the area, for the above reasons, is considered likely territory for oil and gas accumulation.

GLOSSARY

Coarsely crystalline:	Crystals can be seen with naked eye.
Coarse-grained:	Grains 1 mm to 5 mm in diameter. Grains above 5 mm are pebbles.
Cryptocrystalline:	Crystals cannot be seen with hand lens.
Finely crystalline:	Crystals can be seen with hand lens, but not with naked eye.
Fine-grained:	Grain size .25 mm or smaller, but still discernible to the naked eye.
Lapilli:	Small cindery pyroclastic fragments from .5 cm to 3 cm.
Medium-bedded:	Thickness of beds from 6 inches to 12 inches.
Medium-grained:	Grain size from .25 mm to 1 mm in diameter.
Mudstone:	An indurated, non-laminated sediment composed of clay-minerals and other constituents of the mud grade. No granular texture can be seen with a hand lens.
Shale:	Same as mudstone, except for fissility.
Siltstone:	Similar to mudstone except the granular texture can be seen with a hand lens.
Thick-bedded:	Thickness of beds greater than 1 foot.
Thin-bedded:	Thickness of beds from a fraction of an inch to 6 inches.

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PERMIAN STRATIGRAPHIC COLUMN, CABALLO MTS.

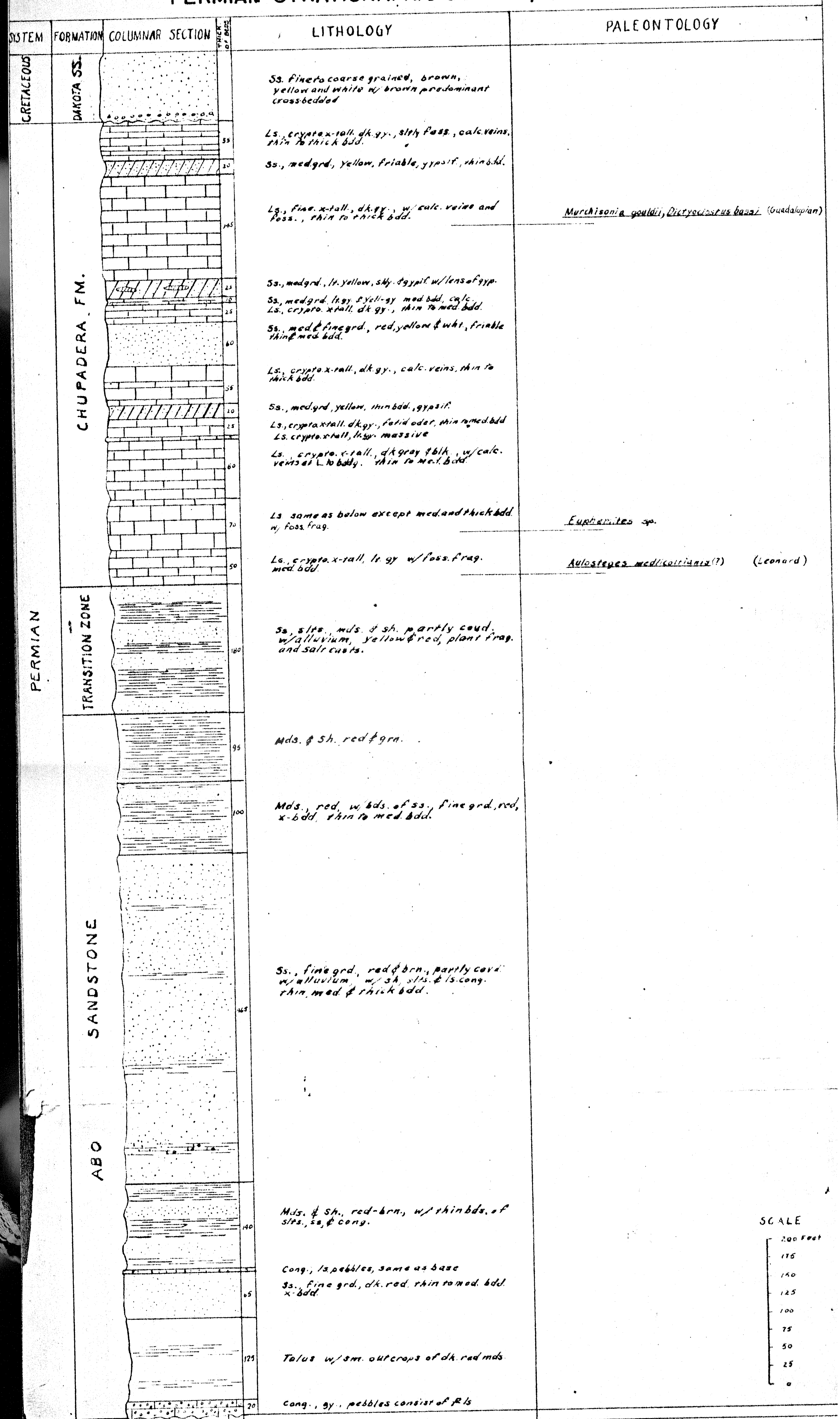
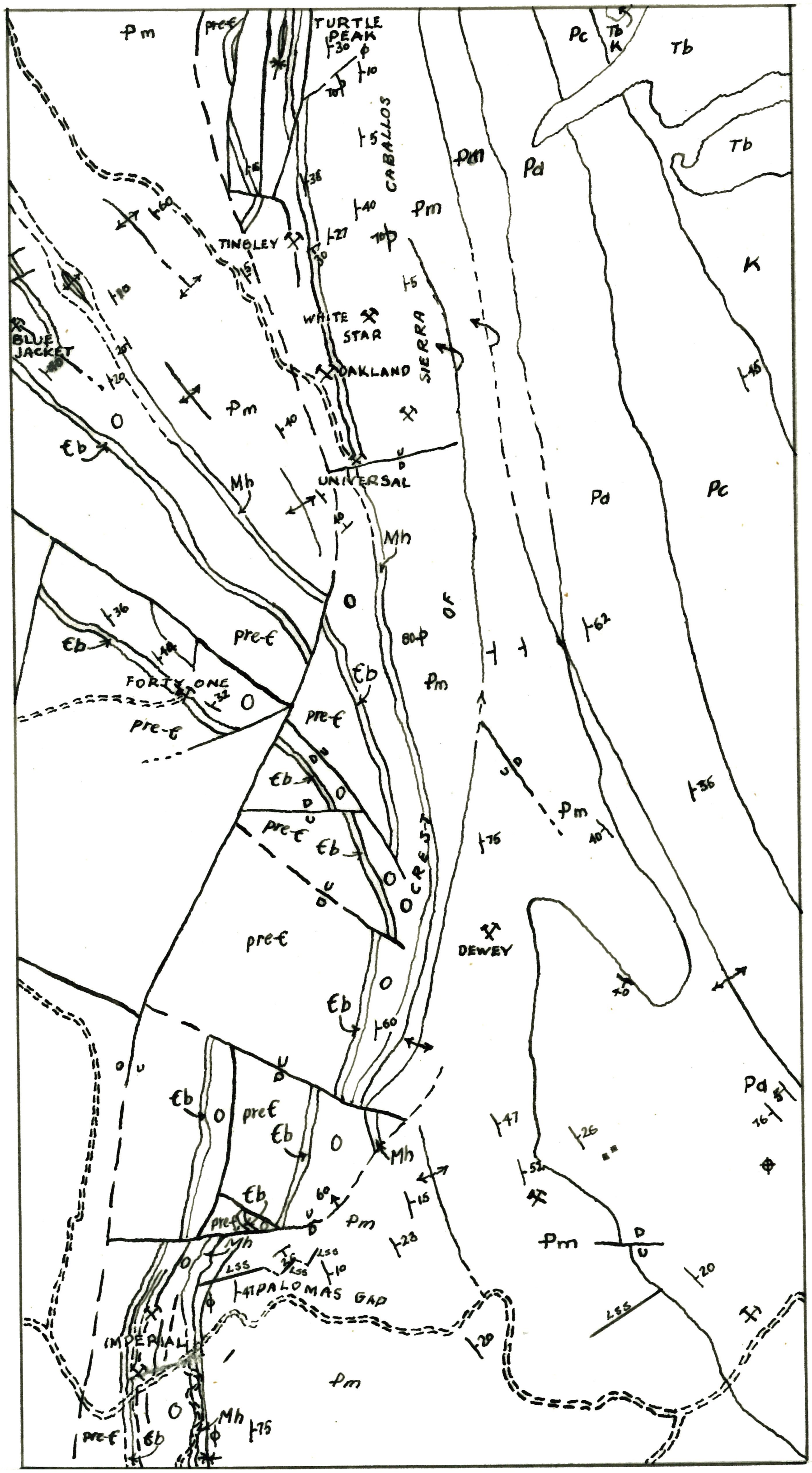


PLATE 7

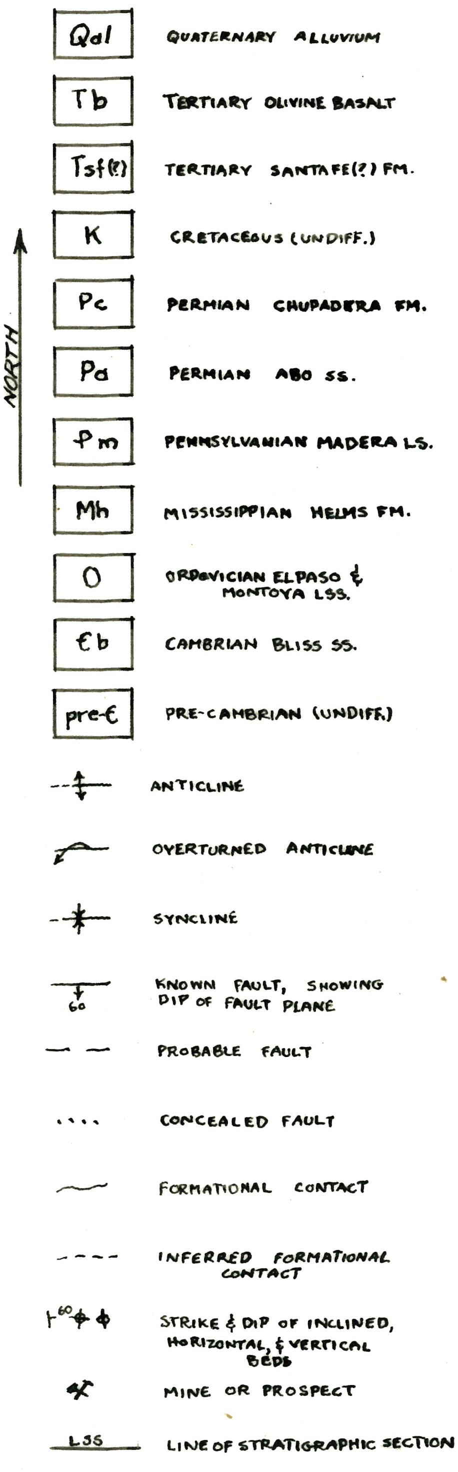
GEOLOGIC MAP OF A PORTION OF THE NORTHERN SIERRA CABALLOS, N. MEX.

0 1/4 1/2 1
SCALE IN MILES

GEOLOGY BY J. C. DOYLE
1950



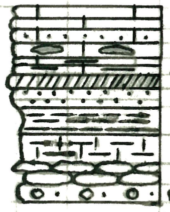
LEGEND



SIERRA CABALLOS STRATIGRAPHIC SECTIONS

EXPLANATION

GRAPHIC SYMBOLS



COLOR

Color appearing immediately after rock name refers to fresh surface.

BEDDING

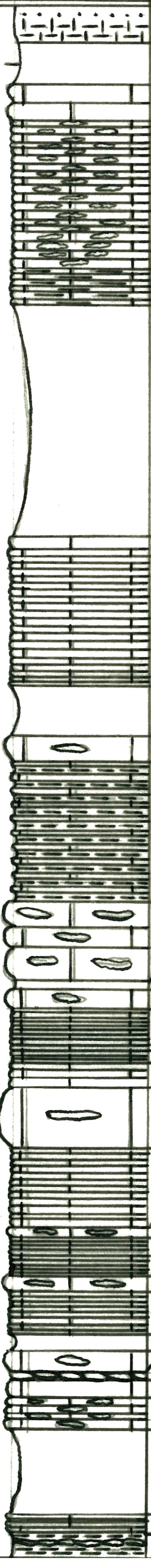
Represented to scale in sections unless otherwise noted in "LITHOLOGY" column. "Shale" refers only to fissile beds of material of clay size.

TEXTURAL TERMS

Crypto-: no grains visible to naked eye.
Finely: grains visible to naked eye but not measurable.
Meso-: measurable to 2 mm. diameter.
Coarsely: greater than 2 mm. diameter.
Crystalline: exhibiting good crystal faces.
Granular: exhibiting poor crystal faces because of clastic origin, etc.

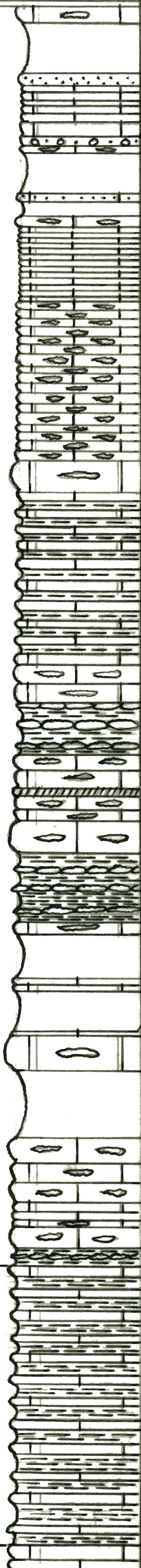
PALEONTOLOGY

Names of Bryozoan species have been omitted from the sections.
(r) Rare (c) Common (a) Abundant



SYSTEM	SERIES	UNIT	SCALE (FEET)	LITHOLOGY	PALEONTOLOGY
PERMIAN	WOLFCAMP	63		Red sandstone & mudstone (Abo formation).	
PENNSYLVANIAN	DES MOINES AND/OR MISSOURI	62	80	Covered.	
		61	70	Limestone: medium gray, weathers light gray; finely crystalline	No fossils found.
		60	60, 50, 40, 30	Limestone: black, weathers light brown; cryptocrystalline; beds 4 in. to 2 ft. thick; dark gray chert finely disseminated.	No fossils found.
		59	20	Limestone: light gray, weathers buff; mesogranular, light gray chert nodules <1 cm. diameter.	crinoid columnals (a)
		58	10	Limestone: black, weathers reddish brown; cryptocrystalline; argillaceous.	No fossils found.
		57	800, 90, 80, 70, 60, 50	Covered.	
		56	40	Limestone: light gray, weathers light gray; finely to crypto-crystalline	No fossils found.
		55	30, 20, 10	Limestone: black, weathers reddish brown; finely crystalline, beds 3 in. to 1 ft. thick.	Buxtonia sabricula (?) (r).
		54	700	Covered.	
		53	90	Limestone: grayish brown, weathers light gray; finely crystalline; with light gray chert nodules < 5 cm. diameter.	No fossils found.
		52	80, 70	Limestone: black, weathers buff; cryptocrystalline; beds 6 in. to 1 ft. thick.	No fossils found.
			60, 50	Shale: black; soft; beds 1 to 3 in. thick.	
		51	40, 30	Limestone: dark gray, weathers buff; finely crystalline; with dark gray chert nodules < 10 cm. thick, < 60 cm. long.	No fossils found.
		50		Covered.	
		49	20	Limestone: light gray, weathers light gray; finely crystalline; with light gray chert nodules < 7.5 cm. diameter.	No fossils found.
		48	10	Limestone: black, weathers light gray; cryptocrystalline; beds 6 in. to 1 ft. thick.	Unusable fossil fragments.
		47	600	Limestone: black, weathers light gray; cryptocrystalline.	No fossils found.
		46	90, 80	Limestone: black, weathers buff; cryptocrystalline; with dark gray chert nodules < 16 cm. thick, < 60 cm. long.	No fossils found.
		45	70	Limestone: black, weathers light gray; cryptocrystalline; beds 3 to 6 in. thick.	Dictyoclastus americanus (r).
		44	60	Limestone: dark gray, weathers light gray; finely crystalline; with light gray chert nodules < 15 cm. diameter.	Composita sp. (r).
		43	50	Limestone: black, weathers buff; cryptocrystalline; beds 6 in. to 1 ft. thick.	No fossils found.
		42	40	Limestone: light gray, weathers buff; finely crystalline; with light gray chert nodules < 30 cm. diameter.	No fossils found.
		41	30	Limestone: black, weathers buff; cryptocrystalline.	No fossils found.
		40		Covered.	
		39	20	Limestone: light gray, weathers dark gray; finely crystalline; with dark gray chert nodules < 15 cm. diameter.	No fossils found.
		38		Limestone: black, weathers gray; cryptocrystalline; nodules < 45 cm. thick, < 30 cm. long.	No fossils found.
		37	10	Limestone: light gray, weathers dark gray; finely granular; clastic.	crinoid columnal fragments (c)
		36	500	Limestone: dark gray, weathers buff; cryptocrystalline; 15% finely disseminated light gray chert.	No fossils found.
		35	90, 80	Covered.	
		34		Limestone: light gray, weathers buff; finely granular.	small crinoid columnals (a).
		33	70	Shale: olive green, soft.	
				Limestone: black, weathers buff; cryptocrystalline; nodules < 30 cm. diameter.	No fossils found.

SIERRA CABALLOS - STRATIGRAPHIC SECTIONS



SYSTEM	SERIES	UNIT	LITHOLOGY	PALEONTOLOGY
PENNSYLVANIAN	DES MOINES	32	Limestone: light gray, weathers medium gray; finely crystalline; with medium gray chert nodules < 3 cm. thick, < 35 cm. long.	*Composita* sp. (r).
		31	Covered.	
		30	Sandstone: light gray; 70% subrounded quartz grains < 1.5 mm. diameter; 30% calcite.	small silicified crinoid columnals (a)
		29	Limestone: light gray, weathers gray; finely granular.	*Composita* sp. (r).
		28	Conglomerate: limestone pebbles & cobbles < 6 cm. diameter in matrix of silt (60%).	No fossils found.
		27	Limestone: light gray, weathers buff; finely crystalline; 5% light gray chert nodules < 2 cm. diameter.	No fossils found.
		26	Covered.	
		25	Limestone: dark gray, weathers dark gray; finely crystalline; 10% rounded quartz grains < 2 mm. diameter.	No fossils found.
		24	Covered.	
		23	Limestone: light gray, weathers buff; finely crystalline; with light gray chert nodules < 15 cm. diameter.	Bryozoa only.
		22	Limestone: black, weathers buff; cryptocrystalline; slabby; in bed 3 in. to 1 ft. thick.	*Dictyoclostus americanus*? (r). *Spirifer occidentalis* (r).
		21	Limestone: medium gray, weathers buff; finely crystalline; 20% black chert nodules < 10 cm. diameter; beds 2 to 4 ft. thick.	*Caninia torquia* (r).
		20	Limestone: black, weathers light gray; cryptocrystalline; with black chert nodules < 20 cm. diameter.	*Lophophyllidium prolifera* (r) *Hustedia mormoni* (r).
		19	Limestone: light gray, weathers light gray; finely crystalline; beds 2 to 3 ft. thick.	*Composita* sp. (r)
			Shale: dark gray; soft; beds 0.5 to 1.5 ft. thick.	*Spirifer occidentalis* (r).
		18	Limestone: light gray, weathers light gray; finely crystalline; 30% light gray chert nodules < 1 cm. diameter.	No fossils found.
		17	Limestone: black, weathers buff; cryptocrystalline; nodules < 12 cm. long, < 10 cm. thick. Shale: olive brown; soft; beds 2 to 4 in. thick.	*Echinoconchus semipunctatus* (r) *Neospirifer triplicatus* var. *alatus*. (r).
		16	Limestone: dark gray, weathers buff; cryptocrystalline; with black chert nodules < 15 cm. diameter. Chert: black.	No fossils found.
		15	Limestone: dark gray, weathers light gray; finely crystalline; with light gray chert nodules < 5 cm. diameter.	Bryozoa only.
		14	Shale: black; hard; beds 1 to 3 in. thick. Limestone: black, weathers light gray; cryptocrystalline; nodules 7 to 15 cm. thick, 10 to 20 cm. long.	*Fusulina* sp. (r).
		13	Limestone: black, weathers medium gray; finely crystalline; with dark gray chert nodules < 10 cm. diameter.	*Fusulina* sp. (r). crinoid columnal *excentricus* (r).
		12	Covered.	
		11	Limestone: light gray, weathers light gray; finely crystalline.	*Syringopora multattenuata* (c).
		10	Covered.	
		9	Limestone: black, weathers light gray; finely crystalline.	*Lophophyllidium prolifera* (r).
		8	Limestone: dark gray, weathers light gray; finely crystalline; with light gray chert nodules < 5 cm. diameter.	*Lophophyllidium prolifera* (r).
		7	Covered.	
		6	Limestone: black, weathers light gray; cryptocrystalline; with black chert nodules < 15 cm. thick, < 60 cm. long.	*Fusulina* sp. (c).
		5	Limestone: light brownish gray, weathers buff; cryptocrystalline.	*Fusulina* sp. (c) *Wedekindellina* sp. (c).
		4	Limestone: black, weathers light gray; cryptocrystalline; with dark gray chert nodules < 7 cm. thick, < 45 cm. long.	No fossils found.
		3		
	DERRY ?	2	Limestone: black, weathers buff; finely crystalline; nodules < 5 cm. thick, < 10 cm. long. Shale: dark gray, hard; calcareous.	*Composita subtilita* (r). *Linoproductus missouriensis* (r) *Spirifer occidentalis* (r).
		1	Limestone: light gray, weathers light gray; cryptocrystalline.	No fossils found.
			Shale: brownish gray; hard; calcareous; beds 4 to 6 inches thick.	*Derbyia crassa* (c). *Spirifer occidentalis* (c)
			Limestone: dark gray, weathers light gray; cryptocrystalline; beds 3 to 4 inches thick.	*Acanthopecten carboniferous* (r). *Myalina perattenuata* (r).
MISSISSIPPIAN	CHESTER ?	0	Limestone: medium brownish gray, weathers buff; finely crystalline.	*Neozaphrentis* sp. (c). *Orthotetes kaskaskiensis* (r) *Dictyoclostus inflatus* (c). *Spirifer increbescens*? (r).