GEOLOGIC MAP 19

Description, Geologic Map of the Tierra Amarilla Quadrangle, Rio Arriba County, New Mexico

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Introduction

The Tierra Amarilla quadrangle in central northern Rio Arriba County lies near the eastern edge of the Navajo section of the Colorado Plateaus physiographic province. Most of the quadrangle is within the Tierra Amarilla Land Grant, which has long been divided into smaller parcels with a multiplicity of ownership. The town of Tierra Amarilla, county seat of Rio Arriba County, and the towns of Park View and Ensenada, all in the northeastern quarter of the quadrangle, are population centers of the irrigated farmlands along the Rio Chama, Rio Brazos, and Rito de Tierra Amarilla. El Vado is the center of a resort and recreation area around El Vado Reservoir. The remainder of the area is mostly sparsely populated grazing land.

Altitudes within the quadrangle range from less than 6600 feet where the Rio Chama leaves the quadrangle in the southwestern corner to more than 8600 feet near the eastern edge about 3 miles southeast of Tierra Amarilla. Local relief seldom exceeds 400 feet, except where the Rio Chama has cut through the resistant Dakota Sandstone to depths of as much as 800 feet and where the Dakota-armored domal and anticlinal uplifts in the western part of the quadrangle rise as much as 1000 feet above the surrounding area.

Many early Spanish explorations and later U.S. Government-sponsored explorations and surveys passed through the area of the Tierra Amarilla quadrangle (Dane, 1960a). Part of the quadrangle was mapped by Dane (1948), and the geology and structure of the area including the quadrangle were discussed and shown by Dane (1960b), Muehlberger (1960), and Smith and Muehlberger (1960). Field work for the present report was done by the authors in 1964 and 1965; small areas were rechecked during 1966.

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Stratigraphy

Rock units exposed in the quadrangle range in age from Late Jurassic to Recent. Oil and gas exploration wells drilled in and adjacent to the quadrangle (Bieberman, 1960) show that the Precambrian basement rocks that underlie it (Foster and Stipp, 1961) are overlain by rocks of Pennsylvanian, Permian, Triassic, and Jurassic age that are exposed at only a few places in the immediate area (Smith, Budding, and Pitrat, 1961; Muehlberger et al., 1960). The thickness of these unexposed rocks in the general area ranges from a few hundred feet to more than 4000 feet, but because of a shortage of subsurface information, the distribution of these rock units within the boundaries of the quadrangle is practically unknown. Therefore, the following discussion is confined to those rock units that crop out in the Tierra Amarilla quadrangle.

LATE JURASSIC

MORRISON FORMATION (Jm) (375+ ft thick, lower part not exposed)

The Morrison Formation, though not examined in detail, includes a varied assemblage of mudstone, sandstone, and conglomeratic sandstone. Mudstone is gray, grayish green, and reddish brown. Sandstone and conglomeratic sandstone are light gray, grayish green, and buff and generally weather to darker shades of these colors. They range from soft, weakly cemented, crumbly, fine-grained sandstone to medium-grained sandstone with numerous rounded to subrounded pebbles as much as an inch in diameter, composed of chert, quartz, and quartzite and, locally, of fragments and chunks of grayish to bright-green claystone, siltstone, and very fine-grained silty sandstone. Some of the beds are markedly lenticular channel fillings; others are more regularly bedded and range from a few feet to more than 20 feet thick, with irregular or undulating scoured surfaces at the base. Many of the thicker beds are conspicuously cross-bedded. There are a few beds of thin- to medium-bedded, dense gray limestone that weathers dark gray or brown. The Morrison crops out in a very steep slope beneath cliffs made by the overlying sandstone beds.

EARLY(?) AND LATE CRETACEOUS

BURRO CANYON(?) FORMATION AND DAKOTA SANDSTONE (Kdb) (300 to 325 ft thick)

A unit from 55 to 85 feet thick, consisting principally of conglomeratic sandstone, is probably equivalent to the Burro Canyon Formation, as McPeek (1965) suggested. Dane (1948, 1960b) previously included this unit in the Morrison Formation, but on the present map it was included with the overlying Dakota Sandstone, from which it is not readily separated in mapping although it is recognizable as a distinct unit on close examination or in measuring sections.

In Rio Chama Canyon at North El Vado Dome, the basal conglomeratic sandstone unit consists, in ascending order, of 36 feet of gray, brown-weathering, coarse-grained sandstone, conglomeratic sandstone, and pebble conglomerate; 15 feet of light-gray, brown-weathering, fine-grained sandstone, in part cross-bedded, containing a few stringers of scattered pebbles; and 4 feet of earthy, greenish, soft sandstone at the top. Pebbles in conglomeratic parts are black, white, red, and gray and are composed of quartz, quartzite, and, dominantly, of dense siliceous material. Maximum pebble dimension is about 1 inch. In the basal part of the unit are angular blocks, as much as 8 inches on a side, of soft green, very fine-grained, clayey sandstone. Cross-bedding at angles up to 20 degrees is traceable for distances of as much as 3 feet. Beds of this unit are cemented with silica to varying degrees and form several resistant ledges that generally make a cliff above the steep slopes of the underlying Morrison Formation.

The overlying Dakota Sandstone consists of alternating tan- to brown-weathering sandstone in beds ranging from a few feet to 60 feet thick and dark-gray carbonaceous shale and siltstone in beds ranging from thin sheets and stringers to 35 feet thick. The shale and siltstone beds in places amount to as much as one third of the total thickness of the formation. Carbonaceous material is characteristically present throughout beds of the Dakota in amounts ranging from small specks, flakes, and charcoal fragments in some sandstone beds to carbonaceous and coaly shales. Sandstone ranges from very fine-grained to granule-sized and contains some small, dense, siliceous pebbles similar to those more common in the lower beds. Sandstone ranges from friable and weakly cemented to well cemented, and some, especially in the upper part, is so thoroughly cemented by silica as to be quartzite. The sandstone is thin-bedded to thick-bedded and massive and locally cross-bedded. Ripples with a wave length of 2 to 3 inches mark some beds. Many sandstone beds contain numerous tubular borings, presumably burrowings of marine worms or other organisms. On fresh fracture, the sandstone is generally light gray or pale tan but it weathers to darker colors. Thick beds make cliffy ledges, and the formation as a whole weathers to a steep or vertical cliff where it caps the canyon walls of the Rio Chama. A sandstone bed 2 to 3 feet thick overlying a poorly exposed, soft, dark, silty shale unit 20 to 40 feet thick forms the top of the formation in the northern part of the quadrangle. This highest sandstone bed in places weathers back considerable distances from the next underlying thick sandstone ledge of the formation and for this reason may locally appear to be absent.

LATE CRETACEOUS

Mancos Shale (2000± ft thick)

The Mancos Shale of the Tierra Amarilla quadrangle and adjoining areas contains lithologic equivalents of parts of the Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Formation as these rock units have been distinguished in northeastern New Mexico and eastern Colorado. In most previous mapping and stratigraphic studies in the northeastern part of the San Juan Basin, some of or all the units have been differentiated as members of the Mancos Shale. However, mapping in the Tierra Amarilla quadrangle and stratigraphic studies there and elsewhere (Muehlberger et al.) have shown that lithologic contacts of the beds of Niobrara age cannot be precisely located. Accordingly, *Carlile* and *Niobrara* are dropped as member names in this area. Two sandstone units of Niobrara age have been defined and mapped; the Juana Lopez Member of Carlile age has also been mapped across the quadrangle. The Graneros Shale and Greenhorn Limestone members are retained and mapped, but it is recognized that they are not wholly time-equivalent to these units at their type localities and elsewhere in eastern Colorado and western Kansas (Hattin, 1965, p. 11-15).

Much of the Mancos Shale is poorly exposed, and there are few places where complete sections of several of the softer parts of the formation can be measured. Accurate thicknesses are difficult to determine because the relative width of outcrop is great compared with thickness of strata and because poor exposures, low dips with slight local variations, slumping, and structural irregularities make it difficult to determine the true stratal attitude. Under these circumstances, some of the thicknesses given are not precise; a given range in thickness may be due either to inaccurate determinations or to actual change in thickness of the unit from place to place.

Graneros Shale Member (Kmg) (135 to 150 ft thick)

The Graneros Shale Member of the Mancos Shale is a soft unit 135 to 150 feet thick. Though generally poorly exposed for much of its thickness, several persistent and distinctive zones and beds nevertheless may be recognized throughout the quadrangle. Some of these are known or presumed to be persistent for much greater distances.

Near the base, two zones contain large, brown, clayey, silty limestone concretions composed of an aggregate of subspheroidal masses a few inches in diameter that have radial structure and, not uncommonly, incipient cone-in-cone structure. These concretions lie along two persistent bentonite beds a few inches thick that are stratigraphically 10 feet apart in the northern part of the quadrangle and 25 feet apart in the southern part. The lowest bentonite bed is 1 to 15 feet above the top ledge of the Dakota Sandstone. Beds below and between these persistent bentonite beds are dark silty shale or siltstone.

The overlying part of the Graneros Shale Member is chiefly dark-gray, calcareous shale, but it contains about a dozen beds of bentonite, ranging from a fraction of an inch to several inches thick, and several beds of light-gray, dense carbonate concretions. About in the middle of the member are several beds of hard calcareous siltstone less than 1 inch thick in a zone about 2 feet thick. About 25 feet below the top of the Graneros is a rather conspicuous, white-weathering, platy, or flaky-weathering limestone bed about a foot thick in which the fossil *Inoceramus pictus* commonly occurs; 5 to 8 feet below the top, in an equally persistent but far less conspicuous zone (less than a foot thick), nodular gray limestone concretions contain *Sciponoceras gracile*. Much of the Graneros Shale Member mapped in the Tierra Amarilla quadrangle is equivalent to the lower part of the Greenhorn faunal zone as recognized in the Pueblo, Colorado, area and in western Kansas (Hattin, p. 11-15; Scott, 1964).

Greenhorn Limestone Member (Kmgr) 45 to 60 ft thick

The lower one half to two thirds of the Greenhorn Limestone Member of the Mancos Shale consists of limestone beds a few inches to 2 feet thick alternating with beds of very calcareous shale a few inches to 3 feet thick. Limestone comprises somewhat less than half of this part of the member. The upper part of the Greenhorn is composed almost entirely of calcareous shale like that in the lower part, but it contains, in places, a few beds, ranging in thickness from a fraction of an inch to a few inches, of globigerinal limestone or limestone composed largely of *Inoceramus* prisms. The dense, finely crystalline limestone beds of the Greenhorn are light bluish gray to medium gray on fresh fracture but weather yellowish gray to nearly white. The intervening calcareous shales are medium dark gray to olive-gray on fresh fracture and weather bluish gray. The limestone characteristically contains impressions of *Inoceramus labiatus* and some ammonite impressions; the fauna is of late Greenhorn age.

Lower Shale Unit (Kml) (170 to 210 ft thick)

The Greenhorn is succeeded by a shale unit that includes a lower part of brownish-gray shale and siltstone and an upper part of very dark-gray shale with septarian concretions.

The lower part, about 70 feet thick, is mostly light brownish-gray to light olive-gray somewhat calcareous shale that weathers pale yellowish brown, in marked contrast to the bluish- or whitish-gray, harder, more calcareous shale of the underlying Greenhorn. The shale contains fragments of fish scales, impressions of juvenile *Collignoniceras woollgari,* and some small oysters. In most places, numerous siltstone beds a fraction of an inch to a few inches thick become locally thicker, harder, and more abundant so that part of the unit may make a low ridge. The lower 15 feet of the unit contain 3 pairs of bentonite beds, each bed 1 to 5 inches thick, with the lowest at the base of the unit.

The lower brownish-gray shale and siltstone is succeeded by about 80 to 140 feet of very dark-gray to black shale, the lower part of which is very poorly exposed. The upper part of this dark shale contains septarian limestone concretions that weather yellowish gray to grayish orange. The concretions are one foot to several feet thick and as much as 5 feet across, and the septa are composed of brown crystalline carbonate. No fossils were collected from this black shale and septarian concretion unit in the Tierra Amarilla quadrangle, but farther south in La Ventana quadrangle and adjoining areas, these beds contain several species of ammonites including *Prionocyclus hyatti* (W. A. Cobban, oral communication, 1965).

Juana Lopez Member (Kmjl) (90 to 125 ft thick)

The Juana Lopez Member consists dominantly of dark-gray to very dark-gray shale. It is distinguished, particularly near the top and the bottom, by beds of hard, very fine-grained calcarenite that weather grayish orange to pale yellowish brown and range in thickness from a fraction of an inch to several inches. The calcarenites consist of carbonate-cemented bioclastic material, mostly broken and worn prisms from *Inoceramus* shells. Trails, casts, or small ripples mark many of the beds. Other beds contain numerous fragments of or complete fossils. Some beds, particularly in the lower part, contain fish scales, teeth, and bone fragments, and a few contain a small amount of silt or very fine grains of quartz. In the shalier middle part, limestone concretions as much as 1 foot thick and 3 feet across, weather grayish orange. The Juana Lopez is abundantly fossiliferous and can be divided into several faunal zones (Dane, Cobban, and Kauffman, 1966). The fauna includes *Prionocyclus macombi, Prionccyclus wyomingensis, Scaphites warreni, Inoceramus dimidius, Lucina* sp., and *Lopha* (formerly *Ostrea*) *lugubris. Scaphites whitfieldi* and *Inoceramus perplexus* occur in the uppermost beds.

Middle Shale Unit (Kmm) (230 to 280 ft thick)

The top of the Juana Lopez Member nearly everywhere in the quadrangle forms a dip slope above which succeeding beds are very poorly exposed. Where seen, they are dark-gray, fissile shale containing in the basal part a marine fauna like that of the youngest faunal zone of the underlying Juana Lopez Member. Only a few feet of these beds are exposed. The overlying shale consists of finely micaceous, olive-gray, silty shale that weathers medium gray, contains minute carbonaceous plant fragments, and has a blocky or chunky fracture. The base of beds of Niobrara age occurs at an as yet undetermined level in the shale. In the southeastern part of the Tierra Amarilla quadrangle and in discontinuous outcrops in the Boulder Lake quadrangle to the west, this shale is succeeded by a thin, medium- to coarse-grained, glauconitic sandstone. The thickness of the lower part of the middle shale unit between the glauconitic sandstone, herein designated the Cooper Arroyo Sandstone Member of the Mancos Shale, and the Juana Lopez Member is probably 80 to 100 feet.

The shale overlying the Cooper Arroyo Sandstone Member is about 150 to 180 feet thick and consists of medium- to dark-gray silty shale, calcareous shale, and a few thin bentonite beds. In the upper and lower parts are a few thin beds of calcareous siltstone less than 1 inch thick, some of which are slightly glauconitic. Richly foraminiferal calcareous shale forms a few thin laminae, and a few beds contain *Inoceramus platinus* encrusted with *Ostrea congesta.*

Cooper Arroyo Sandstone Member (Kmc) (0 to 3½ ft thick)

The Cooper Arroyo Sandstone Member is here named from type outcrops in the Boulder Lake quadrangle, beginning about 650 feet south of Cooper Arroyo and 1400 feet west of the eastern boundary of the quadrangle. Outcrops extend as a low cuesta ridge from there southwestward for about 2 miles with few interruptions. Although thin and local, the sandstone merits a formal name because of its distinctive lithologic character. The type section is located in the Tierra Amarilla Grant, 3000 feet S. 10° W. of the road intersection at BM 6966, which lies 3600 feet south of New Mexico Highway 112, and 500 feet west of the eastern boundary of the Boulder Lake quadrangle.

Section of Cooper Arroyo Sandstone Member at the type section

MIDDLE SHALE UNIT	Ft	In.
Upper part		
Shale, dark gray, silty, calcareous, with float of *Inoceramus platinus,* which occurs in place in beds not many feet higher		
Cooper Arroyo Sandstone Member		
Sandstone, coarse-grained, with a few very coarse grains, in beds ½ in. to 4 in. thick abundantly glauconitic. In cross sections, beds have wavy upper and lower surfaces as though ripple-bedded with a wave length of 3 to 8 in., but		

	Ft	In.
ripple mark not evident on irregular, upper weathered surface. Upper surface marked by smooth-surfaced tubular borings. Contains small, black, dense, siliceous pebbles up to ½ in. in diameter. The thickest coarse bed is cross-bedded at angles of as much as 25 degrees	1	10
Sandstone, medium-grained, abundantly glauconitic, in irregular beds ½ in. to 1½ in. thick, with a very slightly irregular undersurface	0	10½
	2	8½
Lower part		
Shale, silty, olive-gray, micaceous, weathers medium gray, contains minute carbonaceous plant fragments		

At a few localities, the Cooper Arroyo Sandstone Member has a small fauna, identified by W. A. Cobban, that includes *Inoceramus erectus,* which is an index species of early, but not earliest, Niobrara age, *Placenticeras* sp., *Ostrea congesta,* and fish teeth.

El Vado Sandstone Member (Kme) (90 to 100 ft thick)

El Vado Sandstone Member of the Mancos Shale crops out extensively in the eastern part of the quadrangle and is well exposed in prominent westward-facing escarpments both north and south of Rio Nutrias. It is here named from outcrops west of El Vado Reservoir in the Boulder Lake quadrangle, where it makes a conspicuous low escarpment below high cliffs of the Mesaverde Group. The type section was measured in the Boulder Lake quadrangle below the 7388-foot altitude point located 2.4 miles east and 1 mile north of the southwest corner of the Tierra Amarilla Grant and about 2 miles southwest of the emergency overflow outlet for El Vado Reservoir shown on the Tierra Amarilla quadrangle map.

Section of El Vado Sandstone Member at the type section

Upper shale unit	Ft	In.
Shale, medium gray, soft		
El Vado Sandstone Member		
Sandstone, very fine-grained, and siltstone, calcareous, yellowish gray on fresh fracture and weathered surface, some beds harder and more calcareous, beds fraction of an inch to		

	Ft	In.
several inches thick, upper few feet weather back from ledge face. Some ripple bedding	17	0
Shale, medium gray, silty, makes notch	1	0
Sandstone, very fine-grained, and siltstone, forms a ledge with the two overlying units	5	0
Shale, silty, medium gray, forms persistent slope, transitional into overlying unit	27	0
Siltstone, and very fine-grained sandstone, calcareous, thin-bedded, brownish gray, weathers yellowish gray, minutely micaceous, with oyster fragments. Cross-bedding within the unit results in increase of thickness of subunits from 1 to 2 feet along the outcrop. Whole unit makes a ledge that appears to maintain a uniform thickness	10	0
Shale, gray and silty shale, soft, makes a persistent notch in cliff	9	0
Siltstone and very fine-grained sandstone, thin-bedded, calcareous, brownish gray, weathers yellowish gray, minutely micaceous and with many shell fragments	11	0
Shale, medium gray, interbedded with silty shale and siltstone, makes slope or small notch in cliff	6	3
Siltstone, shaly and silty shale, yellowish gray, weathers grayish orange, in beds a small fraction of an inch to one inch thick, base of unit transitional with underlying beds but fairly sharp, unit has more and harder siltstone beds upward	13	7
Total El Vado Sandstone Member	99	10

In exposures in the southeastern part of the Tierra Amarilla quadrangle, north of Rio Nutrias, El Vado Sandstone Member contains more plates of *Inoceramus platinus* encrusted with *Ostrea congesta*, comminuted fish remains, ripple marks, and trail and other marks than are recorded in the type section. This reflects some slight local variation in the lithology of the member, but no significant differences occur and the thickness is nearly the same.

Upper Shale Unit (Kmu) (1200± ft thick)

The upper shale unit of the Mancos Shale has been measured only partly and its approximate thickness of 1200 feet was determined by computation. Somewhat more than the lower half of this unit is of late Niobrara age, as determined by the presence of *Inoceramus platinus,* which, when occurring in large fragments or flat pieces of shell, is usually encrusted by *Ostrea congesta.* At or near the base in the southeastern part of the quadrangle is an oyster coquina siltstone several inches thick with locally abundant fragments of fish bone and teeth. Similar, thinner, oyster coquina beds occur at higher levels. Shales of late Niobrara age are calcareous, fissile, brownish gray and olive-gray. The more calcareous shales weather light gray to white. A few very fine-grained sandstone beds contain small fragments of carbonaceous material. About 80 feet above the base in the southeastern part of the quadrangle is a dark yellowish-orange-weathering, dense, tough, claystone bed a few inches to a foot thick that seems to persist for several miles. The upper part of the beds of late Niobrara age is less calcareous than the lower part but continues to be distinguished by the presence of fragments of *Inoceramus platinus* shells.

About 550 feet below the top of the Mancos Shale, a sequence of medium-gray shale contains large, gray, limestone concretions that weather yellowish orange and contain *Scaphites hippocrepis* and *Stantonoceras* sp., diagnostic of early Montana age. Higher in the unit, sandstone beds are present, in the uppermost part predominating over interbedded shale in a zone transitional into the Point Lookout Sandstone at the base of the overlying Mesaverde Group.

Mesaverde Group (135 to 180 ft thick)

The Mesaverde Group is preserved only in the upland area south and southeast of Tierra Amarilla. Though a threefold subdivision is recognized in adjacent areas, only the Point Lookout Sandstone and the overlying Menefee Formation were mapped in the quadrangle. La Ventana Tongue of the Cliff House Sandstone was not recognized, although equivalent strata may be present in the uppermost part of the Menefee as mapped. The Point Lookout and the lower part of the Menefee are much better exposed than the upper part of the Menefee, which is concealed over much of its extent by vegetation and slumped material. The range in thickness of the group, from 135 to 180 feet, is caused in part by variation in the thickness of strata included in the Point Lookout and in part by uncertainties, due to poor exposures, as to the position of the contact of the Mesaverde and the overlying Lewis Shale.

Point Lookout Sandstone (Kpl) (40 to 60 ft thick)

The Point Lookout Sandstone is composed of light-gray, fine- to very fine-grained sandstone that weathers yellowish gray to grayish yellow and tends to form bold cliffs capping steep slopes formed on the upper shale unit of the Mancos Shale. The upper 5 to 10 feet of the formation almost everywhere form a recessive slope because this part is not so well cemented as the lower part and because it commonly is silty or carbonaceous. Obscure parallel and very low-angle cross-bedding were observed at a few exposures of this upper part.

The lower 35 to 50 feet of the Point Lookout comprise massive, fairly well-cemented sandstone with little or no evidence of bedding except in the lower part where the unit grades by downward transition and lateral tonguing into the underlying Mancos Shale. The uppermost part of the Mancos contains sandstone beds, some of which are tongues of the Point Lookout extending into the dark shales of the Mancos. The contact of the Mancos and the Point Lookout is drawn at the base of the cliff-forming, massive sandstone that crops out as one bed because the intertonguing relationship cannot be shown at the map scale. Accretion of sandstone beds to the base of the Point Lookout causes variation in thickness of the Point Lookout within the quadrangle.

Menefee Formation (Kmf) (95 to 120 ft thick)

The Menefee is composed of a complex interlayering of sedimentary rocks, largely of lagoonal and terrestrial origin, that range from fine-grained, well-bedded to massive sandstone to fissile clay shale and lumpy-bedded claystone to coal. All the rock units are generally silty and carbonaceous to varying degrees and most are very lenticular. As many as 9 coal beds, or very carbonaceous shale beds, are present in the Menefee. The lowermost 10 to 12 feet of the formation are persistently carbonaceous and contain as many as 3 thin coal beds. At most places, no more than one of these 3 beds exceeds 14 inches in thickness, and at many places, none is that thick. The thickest of the 3 beds reaches an observed maximum of 49 inches. Another coal bed in this lowermost part is 31 inches thick at one locality. Overlying the lower carbonaceous unit, a persistent ledge-forming sandstone ranges in thickness from about 2 to 7 feet. The remainder of the unit is commonly concealed, but a few exposures indicate that as many as 6 more carbonaceous or coaly horizons are present, interbedded with carbonaceous shale, sandstone, and medium-gray clay shale.

Lewis Shale (Kl) (250+ ft thick)

The Lewis Shale conformably overlies the Mesaverde Group but is so poorly exposed that little can be said of it. The Lewis consists largely of gray, clay shale that weathers yellowish gray, interbedded with a very minor amount of silty, very fine-grained sandstone and sandy siltstone. It contains a few yellow-weathering calcareous concretions as much as 6 feet in maximum dimension. Only the lowest part of the Lewis is exposed in the quadrangle, and the approximate thickness of 250 feet is based largely on geologic inference and is probably a minimum.

QUATERNARY

Gravel Deposits (Qg) (0 to 50(?) ft thick)

Overlying the older consolidated rock units in the quadrangle, unconsolidated gravel deposits cover large areas in the eastern part of the quadrangle and smaller areas in the western part. In places, the deposits are 50 feet or more thick, but in most of the mapped areas, they are probably 10 feet or less. The mapped deposits consist largely of remnants of pediments and terrace deposits related generally but not specifically to the present-day drainage system; that is, the deposits are probably related to earlier stages in the development of the present drainage system. The gravel deposits commonly cap hills that the gravel has protected from erosion. Some of the deposits, particularly those on the sides of hills, are composed largely of colluvium derived from the gravel capping the hills.

The gravel is made up largely of resistant quartzite, mostly derived from Precambrian rocks, together with a variable but small percentage of volcanic rocks. The obvious feature of the deposit is the rounded to subangular, pebble- to small-boulder-sized materials that comprise most of the mapped unit; clay- to granule-sized constituents form a large, but subordinate, part of the deposits in some areas. The source of most of the gravel was the Brazos uplift east of the Tierra Amarilla quadrangle, but some of the gravel deposits in the northern part of the quadrangle may have been derived from the San Juan Mountains northeast of the quadrangle.

Basalt (Qb) (50(?) ft thick)

A fingerlike body of soda-rich olivine basalt extends into the Tierra Amarilla quadrangle from the east and occupies a former valley of the Rio Brazos, which now skirts the north edge of the basalt flow and joins the Rio Chama near the north edge of the quadrangle. At the distal end of the flow, the Rio Chama is joined by the Rito de Tierra Amarilla, which occupies a valley excavated along the south edge of the flow from the town of Tierra Amarilla to the junction with the Rio Chama. The Rito de Tierra Amarilla valley above Tierra Amarilla is older than the downstream part and was occupied by a stream that emptied into the prebasalt course of the Rio Brazos. The flow appears to be as thick as 50 feet or more; its base is almost everywhere concealed beneath basalt talus.

Terrace Deposits (Qt) (0 to 40(?) ft thick)

Terrace deposits mapped in the quadrangle lie above floodplain deposits of the larger streams and, in contrast to the older gravel deposits, are closely related to the present-day stream pattern. The deposits are commonly 3 to 10 feet thick but may reach a thickness of 40 feet or more in some places. Sand- to cobble-sized material comprises the major part of most deposits but clay- and silt-sized material is locally dominant. Composition of the terrace deposits is generally similar to that of the older gravel of the area because clasts are in part derived from the older deposits. The terrace deposits, however, have a larger percentage of finer material and contain more locally derived resistant rock, such as pieces of Dakota Sandstone and Greenhorn Limestone Member of the Mancos Shale.

Landslide Deposits (Qls) (0 to 100+ ft thick)

In a few places, masses of the upper part of the Dakota Sandstone have become detached from outcrops and have moved downhill as chaotic but coherent bodies sliding, presumably, on some of the clay shale beds in the middle part of the Dakota. In most places, the thickness of the beds involved is probably less than 100 feet, but where the jumbled sandstone beds have overridden each other, the thickness may be considerably more. These landslide deposits are potentially unstable.

Alluvium (Qal) (0 to 50(?) ft thick)

Alluvial deposits consisting of clay, silt, sand, pebbles, and cobbles occur along most of the streams in the quadrangle, though the deposits are not extensive enough to map except along the larger streams. No attempt was made to differentiate floodplain deposits (or floodplain terrace deposits) from alluvium in the flood channels. The lithologic type and grain size of the alluvium are related to rock units exposed along each of the streams or parts of streams; in addition, the present-day alluvium incorporates detritus from the older surficial deposits in different amounts. The thickness of deposits mapped as alluvium is difficult to determine but may be as much as 50 feet or more in a few places.

Structure

The Tierra Amarilla quadrangle lies across the junction of the San Juan Basin and the Chama basin (Kelley, 1950, p. 101) and extends about halfway across the latter. The Chama basin has been called the *Chama embayment* and has been considered a structural platform (Kelley, 1950, p. 103). Muehlberger (p. 109) called it the *Chama platform* and considered it "essentially a structural terrace between the San Juan Basin to the west and the Brazos uplift to the east." Included in the Tierra Amarilla quadrangle are all or parts of a north-south-trending series of domal or anticlinal structures—Horse Lake, Willow Creek, and Rio Chama anticlines, Puente dome, and North and South El Vado domes—that lie along or near the boundary between the San Juan and Chama basins and appear to be on the southern extension of the western limb of the Archuleta anticlinorium (Wood, Kelley, and MacAlpin, 1948) or arch (Kelley, 1957, p. 47) of southern Colorado. Most of the quadrangle lies within the Chama syncline. Structural relief between the lowest part of the Chama syncline and the top of the Horse Lake anticline is more than 2500 feet. Local relief due to folding is more than 1250 feet on the Horse Lake anticline, about 1000 feet on Lagunas dome, 500 feet or more on Puente, North El Vado, and South El Vado domes, and more than 500 feet on the west flank of the Rio Chama anticline.

Though the faulting on the Horse Lake anticline has displaced the Dakota Sandstone as much as 1000 feet, most faults mapped in the quadrangle have displacements of less than 200 feet. All the mapped faults seem to have steeply dipping fault planes—observed dips range from 65 degrees to vertical—and most seem to be normal tensional features. Because of their hard, brittle nature, the Dakota Sandstone and the Greenhorn Limestone Member of the Mancos are the two units most commonly broken by the mapped faults, many of which could be observed for long distances even though displacement might be less than 10 feet. The Graneros Shale Member of the Mancos is involved in much of the faulting because of its position between the Dakota and the Greenhorn and its relative thinness. In some areas, small faults breaking the Dakota or Greenhorn are so numerous that not all could be shown on the map. The relative displacement of the two faults mapped on the southwest flank of Horse Lake anticline could not be determined; these faults could be considered very large open fractures.

A few faults, some with displacements of 100 feet or more, were observed in the area where the part of the Mancos above the Greenhorn crops out. The scarcity of faults in this area compared to the abundance of faults in areas underlain by Greenhorn and older rocks is probably caused partly by much poorer exposures and partly by plastic deformation, rather than breaking, of the softer rocks.

The oil test well—Phillips–Helmerich and Payne El Vado No. 1—drilled on South El Vado dome reached Precambrian rocks at a depth of 2004 feet as reported by Dane (1948) or 1815 feet as reported by Foster and Stipp (p. 30). Other wells in the area (Foster and Stipp, p. 30-31) reach rocks of Precambrian age, but in so doing penetrate sequences of rocks not present at all other places. For example, oil test well Hall No. 1 Silver drilled about 9 miles south-southwest of South El Vado dome well reached Precambrian rocks at a depth of 2256 feet (Foster and Stipp, p. 30) but penetrated a sequence of 1864 feet of limestone and black shale of possible Pennsylvanian age (Lookingbill, 1955, p. 41, 42) that does not appear to be present in South El Vado dome well. Because of the complex depositional and structural regional history prior to deposition of the rocks of Late Cretaceous age, the structure of the older rocks underlying the Tierra Amarilla quadrangle may not be so simple as that of the rocks at the surface, which possibly mask some structural features of considerable displacement or amplitude.

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