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Stratigraphy of the Chama quadrangle, northern Rio Arriba County, New Mexico

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STRATIGRAPHY OF THE CHAMA QUADRANGLE NORTHERN RIO ARRIBA COUNTY, NEW MEXICO[1]

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INTRODUCTION

The Chama quadrangle covers the central Chama platform and exposes many of the Mesozoic rocks that are important oil and gas reservoir rocks of the San Juan Basin. Along the Brazos uplift the underlying Jurassic rocks can be studied. Just east of the Chama quadrangle, in Chavez Canyon, are exposures of marine Pennsylvanian resting unconformably on the Precambrian quartzite and overlapped by basal Upper Triassic beds. These beds were intensely deformed during the Laramide orogeny and deeply eroded. The Blanco Basin formation, the basal Tertiary unit, lies unconformably across the truncated edges of all older units. Resting disconformably on this are units of the San Juan Mountains volcanic pile. Glaciation, extensive landsliding, and stream erosion has produced the existing topography.

The study of the Chama and Brazos Peak quadrangles by Muehlberger and the Cebolla quadrangle by H. H. Doney began during the summer of 1955 under the sponsorship of the New Mexico Bureau of Mines and Mineral Resources. Field work has continued through the succeeding summers. Unpublished M. A. theses on file at The University of Texas by Adams (1957), Trice (1957), Davis (1960), and St. John (1960) furnish detailed information on portions of these quadrangles as well as the adjacent Tierra Amarilla quadrangle. Doney's report on the Cebolla quadrangle is in preparation and will be available as a Ph. D. dissertation and later as a New Mexico Bureau of Mines Bulletin. Preliminary statements of some of his work and that of J. H. Davis in the northwestern Tierra Amarilla quadrangle are included here to show some of the differences in stratigraphy. In addition to the support by the New Mexico Bureau of Mines, gratitude is expressed for grants-in-aid from the Geology Foundation and the University Research Institute, both of The University of Texas.

The scenery of this region is truly spectacular. Sheer cliffs over 2,000 feet high form the bold escarpment at the Brazos Box through which the Brazos River has sliced a deep gorge. Although not as precipitous, the remainder of the mountain front is just as impressive, rising 2,500 to 3,000 feet above the valley floor. The Chama Valley itself is topographically varied with the many resistant formations forming large domes, cuestas, and high cliffs.

STRATIGRAPHY

Mesozoic sedimentary rocks are exposed throughout the Chama quadrangle. The northeastern topographic rim is held up by Cenozoic volcanic and continental clastic rocks. Precambrian quartzite is exposed along the eastern rim where the Cenozoic rocks do not overlap onto the Mesozoic sedimentary section. Table 1 summarizes the pre-Cenozoic stratigraphy of the central Chama platform.

Precambrian

The oldest exposed rocks are Precambrian quartzites that crop out along the eastern margin of the Chama platform in the Brazos uplift. The Brazos, Chavez, and Canones boxes are deep, slot-like canyons cut into these rocks. The quartzite is massive, crossbedded, medium- to coarse-grained, silica-cemented quartz sandstone and pebbly sandstone that has been metamorphosed to garnet grade or higher, as shown by adjacent schistose units. This thick unit (5,000-10,000 feet) can be traced southward for 35 miles from near Chama to the Ortega Mountains near El Rito and is the upper part of the Ortega quartzite of Just (1937) which, as subdivided by Barker (1958), is included as a part of his Kiawa Mountain formation. Other metamorphic and intrusive rocks are exposed in the core of the Tusas Mountains (Just, 1937; Jahns, 1947; Barker, 1958; Butler, 1946; Trice, 1957; Muehlberger and Trice, 1960, this guidebook).

Pennsylvanian

Pennsylvanian rocks are exposed at the mouth of the Chavez Box, 6 miles northeast of Tierra Amarilla (Muehlberger, 1957), in the southwest part of the adjoining Brazos Peak quadrangle. A basal talus is overlain by about 200 feet of pale-red, medium-to very fine-grained quartz sandstone that is cemented with quartz and hematite. These beds thin rapidly to the east as they lap onto the Precambrian surface, as shown, for example, by a 60-foot-thick sequence of sandstone in the middle of the section which thins to 15 feet eastward in a horizontal distance of about 500 feet.

Only the basal 25 feet of the overlying sequence of 150-175 feet of beds is exposed. These beds disconformably overlie the older beds and begin with 10 feet of grayish-red, noncalcareous, coarse-grained (grains angular), arkosic sandstone. Overlying this is 5 feet of grayish-red siltstone and gray nodular limestone. Both the limestone and the siltstone are abundantly fossiliferous. The following fossils constituting a middle Des Moinesian assemblage have been identified (by S. P. Ellison, Jr. and J. Marvin Weller) from these beds:

Wedekindellina euthysepta
Fusulina haworthi
Prismopora sp.
Bryozoa (2 forms other than **Prismopora**)
Mesolobus sp.
Derbya sp.
Dictyoclostus sp.
Spirifer sp.
Neospirifer (juvenile)
Composita sp.
Squamularia perplexa
Punctospirifer kentuckyensis
Crinoid fragments

Ten feet of siltstone and calcareous siltstone overlie the fossiliferous beds. The remainder of the sequence is not exposed.

The probable contact with the overlying Triassic was

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[5]Bureau of Economic Geology, The University of Texas, Austin.

found in only one place where it is disconformable. The fact that the Pennsylvanian beds thicken rapidly westward away from the basement suggests an angular relationship regionally.

Chinle formation

The basal Chinle units of the Mesozoic sequence are exposed along the front of the Brazos uplift between Canonizaria Canyon (a northern branch of Canones Canyon) and the Brazos Box. Except in Chavez Canyon where Pennsylvanian rocks rest on Precambrian, the Chinle formation rests unconformably on a nearly smooth surface cut on Precambrian quartzite. The basal unit in Nestor Canyon (a southern branch of Canones Canyon) is 3 feet of pale-brown, well-cemented, fine-grained quartz siltstone, but in Chavez Canyon it is 25 feet of moderate orange-pink, poorly cemented, pebbly coarse-grained quartz sandstone with quartz pebbles and a hematite cement. Overlying these basal units are about 250 feet of poorly exposed grayish orange-pink siltstone and medium- to coarse-grained arkosic sandstone. The arkose has a salt-and-pepper appearance caused by altered biotite and feldspar altered to clay. These beds are friable, thin bedded, and contain hematite cement.

Forming a persistent ridge throughout the exposed area and found above the beds already described is about 25 feet of coarse-grained arkose and silty sandstone that are cemented with chert and hematite. Red chalcedony cements one bed in Nestor Canyon. These beds characteristically weather into angular, hackly pieces and are spottily bleached to a light greenish gray. The sandstone beds in Nestor Canyon are nearly white and are composed of angular coarse-grained quartz, but those in Chavez Canyon are arkosic.

The upper 150 feet of the Chinle is a poorly exposed sequence of siltstone and arkosic sandstone similar to that already described. The topmost unit exposed in Canones Canyon consists of more than 20 feet of moderate orange-pink, well-sorted, subrounded, massive, cliff-forming quartz siltstone that is slightly friable and has a calcareous cement. Stringers of frosted sand grains outline bedding.

No attempt was made during the geologic mapping to subdivide the Chinle formation. The coarseness of the basal and middle units suggests correlation with the Agua Zarca and Poleo sandstones, respectively, that are recognized at the southern edge of the Chama Basin. Lack of outcrops or well data precludes the possibility of checking on the validity of such correlations. No fossils have yet been found in these beds in the Chama region. Wengerd (1950, p. 67-75) presents a useful summary of Triassic rock units and correlations in the San Juan Basin.

Entrada formation

Disconformably overlying the Chinle, the massive cliff-forming Entrada sandstone is exposed continuously from Canonizaria Canyon to the Brazos Box. To the north of Canonizaria Canyon the deep canyons of Willow Creek and Wolf Creek expose the upper Entrada. A section of Entrada measured in the north wall of Canones Canyon consists of nearly 300 feet of very pale-orange to grayish-orange (with the upper 100 feet being slightly darker), well-rounded, very well-sorted, friable, very fine-grained quartz sandstone. Festoon cross-bed units 3-4 feet thick are separated by silty layers as much as 4 inches thick. Limonite staining is present throughout, although the cement is calcareous. A layer of 2- to 5-inch-thick iron-cemented concretions 40 feet above the base and a layer of current ripple marked beds (apparent direction of current on the surface of the outcrop is west) relieve the monotony of the massvie unit. The upper 100 feet of rock forms cliffs that are blocky in appearance compared to the smooth rounded surfaces of the lower cliffs. The lithology of the two parts is identical although the upper unit may be slightly coarser.

A section of Entrada measured in Chavez Canyon differs from the Canones section in several ways. Its thickness is at most 250 feet, and the color of the lower 100 feet of sandstone is pale reddish brown in contrast to the remainder which is grayish yellow. (This is similar in appearance to the spectacular outcrops near Ghost Ranch along the southern rim of the Chama platform.) In addition the lower unit has a calcareous cement and the upper has a non-calcareous cement. The mineralogy, bedding, and other lithic characteristics are the same for both sections except for the top 40 feet in Chavez Canyon. This upper unit is composed of a grayish-orange, well-cemented, silica-cemented, medium-grained quartz sandstone this is brecciated in the lower 8-10 feet. This brecciated zone has been traced for more than one-half mile northward into the north fork of Chavez Creek where the top 30 feet of the Entrada is brecciated and recemented. In places, the breccia fragments are obviously composed of Precambrian quartzite and the unit appears to be a well-cemented talus in a fine-grained sand matrix. This suggests that the Entrada formation overlaps the earlier sedimentary rocks onto the Precambrian basement. Although not demonstrable in this area, the idea seems plausible because both the Pennsylvanian and Triassic rocks wedge out onto the basement, both contain talus of Precambrian quartzite, and in addition, the overlying Dakota formation appears to do the same in the southwestern part of the Brazos Peak quadrangle. Thus there is good stratigraphic evidence of a persistent high area throughout much of the Mesozoic and late Paleozoic in the region now occupied by the Brazos uplift.

Todilto and Wanakah formations

These formations are either covered or absent throughout the Jurassic outcrop belt from the New Mexico-Colorado state line south to the Brazos box. About 10 feet of crinkly bedded, dark, fetid, thin-bedded limestone that is identical with the Todilto limestone exposures in the Echo Amphitheater, 30 miles south, is exposed along a fault east of the Chavez box and 20 feet is exposed south of the Chavez Canyon divide.

What may be Wanakah equivalents are sandstone beds (mapped as part of the lower Morrison formation) that contain gypsum pebbles and are cemented with calcite. These beds are present from Chavez Canyon to Canones Canyon and range in thickness from 15 to 30 feet. The Todilto limestone was not found throughout this same belt. No Todilto or Wanakah equivalents were recognized north from Canones Canyon to the Colorado state line.

These units are conformable with the underlying Entrada and the overlying Morrison wherever the contacts could be observed and have been included on the geologic map with the Morrison formation.

Morrison formation

The Morrison formation is exposed along the front of the Tusas Mountains from the Brazos box north to the Colorado state line. Within the Chama platform the only exposure of the Morrison formation is in the Chama River Canyon across North El Vado dome.

The formation is composed of interstratified units of mudstone and sandstone, with sandstone more abundant near the base. The basal portion consists of grayish-green to pale-red mudstone interbedded with grayish-green to light-gray, medium-grained, well-sorted, hematite-spotted, parallel-bedded, cliff-forming quartz sandstone. Two sandstone units 10-20 feet thick are present near the base. The sandstones have broad gentle cross-bedding within the individual 2-4 foot thick beds. The upper portion consists of interbedded mudstone and stone in units 2 feet or less in thickness. The mudstone is grayish green to pale red and is somewhat more abundant than the sandstone.

The thickness of the Morrison as computed from maps and cross-sections is about 425 feet. The belt of outcrop is usually a series of steep slopes. The most complete exposure is along Wolf Creek near the Colorado state line.

The age of the Morrison is considered to be Upper Jurassic. (Baker, **et al**, 1936, p. 58-63).

Dakota formation

The Dakota formation is exposed over much of the central Chama platform. All of the major anticlines and domes are topographic highs because erosion has stripped the sediments down to the upper sandstone of the Dakota. Narrow canyons cut into these structural and topographic highs and expose still more of the upper part of the Dakota section.

No attempt was made to subdivide the Dakota formation because most exposures are only of the upper beds. Along the Tusas Mountain front it is possible to map the base of the upper thick sandstone (which may appear to be the same bed that caps the anticlines of the central Chama platform) as a separate unit because of its ridge-forming nature.

The Dakota consists of a cliff-forming lower sandstone member about 185 thick near Chama (only 20 at North El Vado dome) that is very pale orange to pale orange, very fine to coarse grained, locally conglomeratic, thick, crossbedded and parallel-bedded. Apparent channels are common and contain well-rounded light-color chert and quartz pebbles in the basal crossbedded units. A few readings of crossbed directions in Chavez Canyon show a dominance of dip direction between southeast and southwest. Conformably overlying this unit is 100-126 feet of dark-gray, platy, carbonaceous, silty shale and fine-grained sandstone. At Chavez Canyon the lower 30 feet of this unit is composed of greenish-gray siltstone and pale red-purple sandstone that appears to be reworked Morrison. Conformably overlying this unit is a very light-gray, medium- to fine-grained, thick, parallel-bedded, cliff-forming sandstone that ranges from 27 to 45 feet in thickness. This sandstone holds up a second hogback in the Dakota along the front of the Tusas Mountains. Conformably overlying this member is an upper unit that consists chiefly of black platy shale, but contains beds of medium light-gray to light-gray, limonite-stained siltstone. The top few feet consists of a very light-gray, very fine-grained, thin, parallel-bedded, fucoidal sandstone containing pelecypod casts. Where this sandstone is missing the top of the Dakota is picked at the top of the next lower ridge-forming sandstone. Thus part of the change in thickness of the Dakota and overlying Graneros shale in the measured sections is caused by defining the top of the Dakota as the uppermost continuous sandstone. However, all units in the Dakota vary in thickness as traced along strike. The thickness ranges from 230 feet on the North El Vado dome (Davis, 1960), and 280 feet at Chavez Canyon, to 390 feet in the Chama River Canyon near Chama.

Worm burrows are present throughout this upper unit and are commonly present on the upper surface of the next lower sandstone unit. No other fossils were found in the Dakota. In the absence of fossils and because of the gradational nature of the contact with the Graneros, the Dakota formation is included in the Upper Cretaceous (Dane, 1948). The Dakota is composed of floodplain, swamp, and lagoonal deposits except for the upper beds which are littoral and grade into the overlying marine shale of the Mancos (Pike, 1947, p. 8). The Dakota disconformably overlies the Morrison formation, the contact being well exposed along the Chama River canyon near Chama and North El Vado dome.

One distinct characteristic of the Dakota as compared with the Mesaverde is the cleanness of its sandstone beds. The grains are rounded, commonly frosted, and composed dominantly of quartz with minor amounts of feldspar in the middle part, and traces of ilmenite and magnetite. Hematite staining in the upper beds gives the rock a reddish color, a color more pronounced on a weathered surface than on a fresh surface. Quartz overgrowths are common in the upper sandstones and many of the quartz grains in the upper member have two generations of overgrowths, one rounded and one angular.

Several Dakota outcrops on the Brazos Peak quadrangle four miles east of the west front of the Brazos uplift indicate the probabilty that the Dakota here rests on Precambrian. One set of outcrops, one mile east of the head of Canones box, has vertical to steep westerly-dipping Dakota capped by nearly horizontal beds of the basal Tertiary conglomerate. The top of the section is to the west and is cut off by a major normal fault that in the late Cenozoic was down to the west. The north and east contacts are along major landslide masses. The sandstone outcrops are in two parallel belts and if the covered interval between is the shaly portion of the Dakota and not faulted material (as seems probable), the apparent thickness of the Dakota is over 700 feet. No indication of the unit under the Dakota at this locality is possible.

Three miles southeast at the west base of Brazos Peak is a group of exposures of the upper Dakota that are surrounded by glacial deposits. The Dakota is dipping very gently westward and about 50 feet of massive, fine-grained, parallel-bedded, friable, quartz sandstone with minute specks of carbon is exposed. Nearby Precambrian outcrops at the same topographic elevation are here used as evidence of Dakota on Precambrian by normal deposition rather than separating the outcrop from the Precambrian outcrop by major faults for which there is no surface evidence.

Mancos formation

Introduction.—Cross and Purington (1899, p. 4) named the Mancos from exposures near the town of Mancos, Colorado. The term has been applied since to shale units of the Upper Cretaceous in Colorado, Utah, Arizona, and New Mexico. At the type section near Mesa Verde National Park, Colorado, the Mancos is about 2,100 feet thick. Pike (1947, p. 9) measured a section 2,191 feet thick 6 miles west of the type locality. Pike also measured a section 267 feet thick south of the Zuni Indian Reservation whereas thicknesses of 6,000 feet (Pike, 1947, p. 9) are recorded in western Colorado. O'Brien (1956, p. 36) measured an 80-foot section in Apache County, Arizona.

Within the Chama region, the total thickness could not be measured but is from 1,600 to 1,700 feet. Apparently the Mancos is a huge wedge-shaped deposit that has its thickest part in western Colorado and pinches out in east-central Arizona. The Mancos is almost entirely shale with some silty limestone beds, concretions, and contains an abundance of fossils.

Dane (1948) designated 5 members of the Mancos shale along the eastern rim of the San Juan Basin. From oldest to youngest these are: Graneros shale, Greenhorn limestone, Carlile shale, Niobrara calcareous shale, and upper Mancos shale. Although these members are designated as formations in eastern Colorado and northeastern New Mexico, Dane (1948) considers them as members which are "lithologic equivalents" of the formations. In our mapping we grouped the Niobrara calcareous shale and the upper shale members of Dane into upper Mancos undifferentiated.

Graneros shale member.—This member consists of fissile, finely bedded, slightly sandy, clayey shale, that is dark gray to black in color. Calcareous concretions are common in the lower portion of the unit. The concretions vary from 12-18 inches in diameter and stand out vividly because of their contrasting yellowish-gray color. Discontinuous, thin, dark limestone lenses appear in the upper part of the unit. Oyster impressions and casts all of which appear to be of the same species, some as large as 6 inches, are very abundant along the upper bedding surfaces of the limestone.

The following are common fossils found in the Graneros: **Gryphaea newberryi** Stanton, **Exogyra columbella** Meek, **Scaphites vermiformis** Meek and Hayden, and **Inoceramus labiatus** Schlotheim (from Pike, 1947, and Reeside, 1924). Pike (1947, p. 21) discussed the faunal zone immediately overlying the Dakota sandstone, equivalent to Graneros, as characterized by **Gryphaea newberryi** and **Exogyra columbella**. However, these fossils are commonly found in sandy facies and may not be good age indicators as they probably migrated with the strand line.

The marine Graneros is conformably with the underlying Dakota sandstone and the overlying Greenhorn limestone member. A lithic change from fine-grained sandstone to silty shale marks the lower shale boundary. In addition to the lithic changes, a distinct color change also takes place. At the contact, the shale is yellowish tan in contrast to the moderate red color of the underlying Dakota. The upper contact is picked at the lowest occurrence of Greenhorn limestone beds. As at the lower contact, the upper boundary is marked by a distinct lithic and color change. Dark-gray and black shales of the Graneros underlying the whitish-gray limestone of the Greenhorn produce a contact visible even from a distance.

Dane (1948) reported a thickness of 120-130 feet for the Graneros. Graphic solutions at several places generally agree with his thicknesses although two measured sections show 150 and 153 feet thick west and southwest of Chama.

Greenhorn limestone member.—Conformably overlying the Graneros is the Greenhorn limestone member which consists of alternating calcareous shale and limestone beds. The lower contact is easily recognized because dark-gray shale bounds the whitish-gray weathering limestone. Being more resistant than the bounding shale members, the Greenhorn forms low, white ridges. Whitish gray on a weathered surface and dark gray on a fresh surface, it is a thinly bedded, dense, slightly fossiliferous, highly fractured limestone in beds one-foot thick separated by thinner intervals of calcareous shale. A distinct petroliferous odor emanates from the freshly broken rock. Joints are closely spaced and perpendicular to the 4-6-inch-thick bedding.

The limestone is a limonitic **Globigerina** biomicrite that also contains **Mammites** sp. and **Inoceramus** sp. Two fossils commonly found in the Greenhorn are **Inoceramus labiatus** Schlotheim and **Baculites asper** Morton, the former being the guide fossil (Pike, 1947, p. 21), yet they are also found in the Graneros.

Our thicknesses range from 12 feet (northeast of Chama) to 20 feet (near Tecolote Point) and are consistently less than those of Dane (1948) because we included only the group of limestone beds that form a prominent ridge and did not include the thinner and widely-spaced limestone beds above our mapping top for the Greenhorn.

Carlile shale member.—Conformably overlying the Greenhorn is the Carlile shale member, which consists of olive-gray to black shale containing a few bentonite layers and numerous marine fossils. It is a fissle, finely bedded mudstone and claystone, and locally is silty. Normally the color is yellowish gray or light brownish gray; the yellow zones resulting from oxidation or iron-bearing minerals. Thin bentonite beds are scattered throughout the section but seem to occur more frequently in the upper 200 feet. A few siltstone beds occur in the middle part of the section, the terrigenous particles of which are smaller than, but lithologically similar to, the sand-sized particles of the Mesaverde formation. Selenite crystals coat some bedding surfaces and appear as filling along joints. Septarian limestone concretions weather out in the lower half of the unit. They are yellowish brown, oblate, and 1-5 feet wide. The septa exhibit two generations of calcite growth; the older, more abundant, light-brown rhombohedrons surround the later formed, clear-white, cavity-filling crystals.

The Carlile contains a varied fauna; among them are: **Baculites gracilis** Shumard, **Inoceramus dimidius** White, **Inoceramus labiatus** Schlotheim, **Inoceramus "fragilis"** Hall and Meek, **Ostrea lugubris** Conrad, **Prionocyclus wyomingensis** Meek, **Prionotropis woolgari** Mantell, and **Scaphites warreni** Meek and Hayden (Reeside, 1924, p. 11). In addition, worm burrows and fish scales were found.

In the Chama quadrangle, fossiliferous calcareous beds cap low hills and constitute a thin marker zone about 270 feet above the Carlile. Immediately below this zone is a giant septarian concretion zone. The lowest bed is a crossbedded sandy limestone, a few inches thick, and sparsely fossiliferous. Overlying this is a cross-bedded calcarenite a few inches thick, that contains abundant **Ostrea lugubris**. Capping the low hills is a thin grayish-orange, parallel-bedded, calclithite containing **Scaphites warreni, Baculites**, and **Prionocyclus wyomingensis** as well as abundant pelecypods.

The upper contact is not so easily discernible. Because the members occur in areas of low relief and also because the shales readily weather to soil which in turn supports a thick growth of grass, the contact is everywhere concealed and as shown on the geologic map is perhaps accurate to within 50 feet stratigraphically. The characteristics used in the field to distinguish the upper Carlile from the overlying member were the change in color from yellowish

gray or light brown to light gray, sparsely fossiliferous to abundant **Inoceramus grandis** prisms covered with **Ostrea congesta**, and a change from very fine bedding to thicker bedding.

Dane (1948) reported a thickness of approximately 500 feet for the Carlile member. Adams (1957) measured a like amount near Chama, and St. John 1960) measured 434 feet near Tecolote Point.

Upper Mancos undifferentiated.—The upper Mancos undifferentiated has previously been mapped as part of two groups, the Colorado and Montana, in ascending order, by Rankin (1944) and Pike (1947). It has been mapped as two members of the Mancos formation in ascending order, the Niobrara calcareous shale, and upper shale, by Dane 1948). Each of these men separated the units mainly on faunal evidence and gross lithic differences between the units. In the subsurface the top and bottom of the Niobrara is not so distinguishable on electric logs (Bozanic, 1955, p. 93). In closer proximity to the Chama area, Dane (1948) described the Niobrara as a calcareous shale and " . . . the occurrence of **Inoceramus grandis**, even as fragments, is apparently a reliable guide to the recognition of the Niobrara".

The upper Mancos undifferentiated, as used in this report, includes all beds between the Carlile shale and the Mesaverde. It is a calcareous and gypsiferous, finely bedded, highly fissile shale. On a fresh surface the color is dark gray, which weathers to light gray. The lower 200-300 feet is clayey, but upward silt-size particles are present that are mineralogically similar to the sand-size material of the overlying Mesaverde formation. These sandy beds increase toward the top of the unit. This appearance of silt often marks the disappearance of abundant fossils. **Inoceramus grandis** as whole organisms, fragments, or prisms, **Inoceramus deformis, Inoceramus labiatus,** and **Ostrea congesta,** are abundant in the lower part of the unit. About 10-20 feet above the lowest occurrence of abundant **Ostrea** or **Inoceramus**, a yellow-buff, medium- to coarse-grained, calcareous sandstone or sandy calclithite occurs that is 3-12 inches thick where exposed. Septarian calcareous concretions appear in the upper 600 feet, but are most abundant in the upper 400 feet. Often the septa are completely weathered, and the concretions, which are sometimes slightly fossiliferous, are seen only as fragments. Where whole, they attain a maximum diameter of 4 feet, and stand out vividly because of their contrasting yellow-orange color. Sharks' teeth and fish scales may be found in the uppermost part of the unit.

Conformable relations exist between the upper Mancos undifferentiated and both the underlying Carlile member and overlying Mesaverde formation. Dane (1960) presented regional evidence of an unconformity truncating Carlile beds by the basal Niobrara faunal zone in the northern San Juan Basin. Our paleontologic work is inadequate to corroborate the study of Dane. Our lower contact is picked at the change in color from the tan of the Carlile below to the light gray of the upper Mancos undifferentiated above and by the lowest occurrence of **Inoceramus gandis** as fragments or whole organisms. At several localities the sandy calclithite appearing 10-20 feet upwards into the younger unit is the actual contact picked, but due to vegetation, cover and soil creep, this bed is not everywhere exposed to delineate the sharper boundary. The upper contact is picked at the lowest occurrence of massive Mesaverde sandstone. Both above and below this line, lenses of the other unit occur, but neither are persistent enough to be mapped across the area.

The thickness of the upper Mancos undifferentiated was not measured. Much of the unit has slid or slumped and it is a unit that readily exhibits present-day soil creep. Graphically its thickness was determined to be about 1,000 feet. If the Niobrara calcareous shale and upper shale members mapped by Dane (1948) are combined, their total thickness is 1,100-1,300 feet.

Mesaverde group

In the Chama quadrangle the recognized three-fold subdivision of the Mesaverde on the east side of the San Juan Basin breaks down because the Menefee formation, which contains coal and fluvial deposits, feathers out to the northeast of the Monero coalfield (Dane, 1948) and the marine La Ventana tongue of the Cliff House sandstone then rests directly on the marine Point Lookout sandstone.

Clean-cut subdivision is possible on the Tecolote Point syncline and the Chama syncline south of Tierra Amarilla (Doney, unpublished study, 1955) where sharp transitions from the Point Lookout sandstone to the overlying coal-bearing Menefee formation are found. The belt of Mesaverde outcrop ringing Chromo Peak has only 10-15 feet of shale dividing the two massive sandstone units. Exposures in the upper Rio Chamita are poor so that it was not possible to determine whether a middle shale unit was present.

Bed thicknesses range from 39 feet in the upper part of the formation to 2-3 inches near the Mesaverde-Mancos contact along the outcrop belt south of Chromo Peak. Most beds are 3-10 feet thick, the average being 4-5 feet. In general, the thickest beds occur near the middle of the formation. Most bed thicknesses are variable laterally. Along strike, the beds thin and thicken and in places incorporate heterogeneous lithologies. The intertonguing characteristics of the formation account for the changing bed thicknesses in the Chromo Peak area.

Close examination of the outcrops reveals small internal and external features of considerable importance in the Chromo Peak region. The broad cross-beds are more pronounced and abundant in the upper part of the formation. The dip is toward the northeast. Scattered throughout the section, but more abundant in the upper part, are zones 5-10 feet in width which resemble stream channels or subaqueous current channels. They have a darker color and are less tightly cemented than the surrounding rock. Their cementing material is clay and limonite. The channels(?) characteristically contain abundant fossils including sharks' teeth, fish scales, unidentified pelecypod casts, shell fragments, and plant fragments. There is also a slight increase in the grain size relative to that of the adjacent rocks. None of the channels were traced far because of the general outcrop pattern of the formation, but they seem to be oriented in two general directions, northwest-southeast and northeast-southwest. Asymmetrical ripple marks found at several localities indicate a current moving in a N.45° E. direction. On the upper surface of many beds worm burrows occur. They are particularly abundant near the upper and lower contacts of the formation. Randomly oriented, the burrows are usually 3-4 inches long and .25 X .25 inch in diameter. These are the same features that have been widely and erroneously called **Halymenites major.**

"Pocket weathering" is particularly noticeable in the upper part of the formation. Averaging 6-8 inches in

diameter and extending back into the outcrop face from 8-12 inches, these voids occur about 3 to 4 feet apart both vertically and horizontally at several localities.

The lower sandstone (Point Lookout sandstone ?) is yellowish gray to light olive gray, massive, parallel-bedded, clay-, iron-, and calcite-cemented, slightly friable, very fine to fine-grained sandstone. Near the base of the member the rock is silty, but becomes coarser grained upward. It contains a few scattered fossils, mostly sharks teeth and fish scales. The unit thins from 110 feet at Tecolote Point to about 100 feet just west of Chama.

The outcrop belt south and west of Chromo Peak has a consistent thin shale unit (Menefee formation ?) that is medium to dark gray, parallel bedded, alternately shaly siltstone and silty shale. The beds are 1-2 inches thick, but locally siltstone lenses attain a thickness of 6-8 inches. Throughout the member plant fragments, coal fragments, and fish scales are abundant. Resin drops 1/8 inch in diameter are found occasionally. On all bedding surfaces and along all joint surfaces, 1/4-1/2 inch-thick selenite crystals are found. Many of these crystals exhibit perfect "fish-tail" twinning. Large septarian, unfossiliferous, calcareous concretions, 1-3 feet in diameter, occur at the contact with the overlying sandstone member. Bedding goes around the concretions and the shale is compressed under the larger ones. The member varies in thickness from 10 to 15 feet yet is present across the entire area. In the Tecolote Point syncline most of the section exposed is sandstone with a few minor coal beds in the Menefee equivalent.

The upper sandstone member (La Ventana tongue of the Cliff House sandstone?) is a dark yellowish-brown to moderate yellowish-orange, massive, parallel-bedded and cross-bedded, calcite and iron cemented, fine- to very fine-grained sandstone. Normally very thick bedded in the lower part of the member, the beds become thinner toward the top of the formation, and less tightly cemented. The rock contains unidentified pelecypod shells, casts, and internal molds, sharks' teeth, and fish scales, most abundant in the channel(?) zones discussed above. The rock characteristically is, at least in part, limonite cemented and has as part of its constituent minerals hematite and glauconite in abundance. The latter is so abundant, especially in the upper half of this member, that the rock has a mottled appearance. Measured thicknesses range from 110 feet to 155 feet. Part of this variance is attributed to incomplete sections; however, there seems to be a general thinning of the member to the east, but exact amounts were not ascertained.

Both the lower contact with the Mancos and upper contact with the Lewis are gradational. Wherever the contacts are exposed, the relationships of the Mancos and Lewis to the Mesaverde are found to be very similar. The Mancos-Mesaverde contact along New Mexico State Highway 29 north of Chama is typical of that boundary for the entire area. The exact contact is picked at the base of the lowest massive sandstone bed. Several thin siltstone and sandstone beds occur below this horizon but are not laterally persistent. The basal bed is a shaly very fine-grained sandstone with ferruginous cement. It is parallel bedded, 1-2 feet thick, containing some fish scales, sharks' teeth, and a few rod-shaped, rounded shale pebbles of the underlying Mancos. Friable and very fine-grained at the base, the bed becomes firm and coarser grained upward. Worm burrows mark the upper surface of the bed. The Mesaverde-Lewis contact is a near replica of the Mancos-Mesaverde contact in reverse and is typified by that found in the headwaters of Willow Creek. Sandstone beds occur about the contact, but diminish in thickness and regularity upward as well as becoming finer grained. The uppermost massive sandstone bed, the top of which is picked as the formational boundary, is 2-3 feet thick and parallel-bedded. It has ferruginous and calcareous cement, and a diminution of grain size and increase in clay content from bottom to top. Its upper surface is also covered with worm burrows. Shale to sandstone and sandstone to shale, though gradational, mark easily recognizable contacts.

Measured thicknesses of the Mesaverde range from 185 to 370 feet in the eastern San Juan Basin (Dane, 1948). Southwest of Chromo Peak 262 feet were measured; southeast only 218 feet were present. Elsewhere, erosion has stripped the formation so that original thicknesses are not determinable. At Tecolote Point a section extending to the Menefee included 116 feet of rocks.

Lewis formation

South and northwest of the Chama area, Dane (1948) and Wood, et al (1948), respectively, described the Lewis as a gray calcareous shale which intertongues with the underlying Mesaverde formation. Both agree that the lower part of the unit typically contains large, buff-colored, calcareous concretions.

Owing to its extreme fissility much of the Lewis of the area has been and is subjected to conditions conducive to different types of mass movement of material and is consequently mapped as Quaternary landslide. The Lewis is a fissle, dark-gray, parallel-bedded shale containing scattered marine fossils and abundant septarian calcareous concretions. Selenite crystals 1/8 to 1/4 inch thick occur along bedding and joint surfaces. Bedding passes around the primary concretions.

Oblate and light yellowish brown, the concretions range in size from 3 to 8 feet. They occur randomly in the section, but at a few localities they appear to be grouped along particular horizons. The septa are light-brown "dogtooth spar" calcite crystals. Often the septa are weathered and a pile of fragments marks the locality of a former concretion. In general, the concretions are unfossiliferous, but some contain plant fragments, broken shells, and rounded **Inoceramus** prisms typical of the older Mancos shale.

The Lewis formation is underlain by the Mesaverde formation and overlain by the Pictured Cliffs sandstone. Gradational with the Mesaverde, the contact is picked at the highest occurrence of massive Mesaverde sandstone. A few sandstone beds typically occur above this horizon, but they become thinner and discontinuous upwards into the section. The upper contact was not seen, as extensive erosion has removed the upper part of the Lewis.

Contact relations with the Mesaverde, lithology, and the concretions of the Lewis and upper Mancos undifferentiated are so similar that these units must have had a similar history. It is believed that the Lewis was deposited in a neritic environment as opposed to the littoral and near-shore environments of the Mesaverde upper sandstone member. Therefore, the Lewis is the transgressive counterpart to the regressive upper Mancos undifferentiated, relative to the Mesaverde.

Dane (1948) reported a varying thickness of about 2,000 feet to the southwest but the post-erosional Lewis

section remaining around Chromo Peak is estimated to have a maximum thickness of 600 feet and that east of Tierra Amarilla to be on the order of 100 feet (H. H. Doney, unpublished report, 1955).

Tertiary system

The oldest Tertiary rock that crops out in the Chama quadrangle is the Eocene(?) or Oligocene(?) Blanco Basin formation. It is overlain by the lower two formations of the Potosi volcanic series, the Conejos quartz latite and the Treasure Mountain rhyolite.

Blanco Basin formation.—The name Blanco Basin formation was applied by Cross and Larsen (1935, p. 48) to arkosic conglomerate, sandstone, and shale that crops out around the Blanco Basin in the Summitville quadrangle, Colorado. It is disconformably overlain by the Conejos quartz latite and is separated from older rocks by a marked angular unconformity.

Outcrops of the Blanco Basin formation are found in the northeastern part of the quadrangle where they hold up bold cliffs. The most accessible good exposures are along the divide between the Chama River and Wolf Creek. The upper part of the formation is a prominent cliff-forming unit but the lower part is commonly obscured by landslide debris.

The Blanco Basin formation in the Chama quadrangle consists of arkosic conglomerate interbedded with arkosic sandstone and subarkosic siltstone. The colors of each of these components are as follows:

(1) conglomerate ranges from dusky and moderate red to pale and dark yellowish orange.
(2) sandstone varies from pale red to dark yellowish orange.
(3) siltstone ranges from light gray to pale red purple.

Clay is the main cement, but in the conglomerate there is calcite in addition. Thin to massive beds, varying in thickness from less than one foot to more than 25 feet, only occasionally exhibit smooth, well-marked parallel bedding planes. The conglomerate and sandstone is poorly sorted; the siltstone is well sorted. All rocks of the Blanco Basin formation are texturally immature.

Quartz, feldspar, and clay comprise the greatest part of the detritus in the rocks of the Blanco Basin formation. In addition to these minerals there are fragments of granitic and metamorphic rocks.

The quartz is dominantly angular to subangular although there is about one percent of well rounded grains. Most of the quartz is of a recrystallized metamorphic type, but plutonic and injected metamorphic types also occur.

The feldspar is angular to subangular and is of two varieties, orthoclase and microcline. Both varieties show various degrees of weathering. Weathering by kaolinization has altered most of it, but some of it has been altered by chloritization. In the conglomerate some feldspar has been replaced by chlorite.

The clay consists chiefly of kaolinite and hematite. The hematite appears to have replaced kaolinite and is interpreted as being post diagenetic. Rocks of the Blanco Basin formation are red on their weathered surface because of the hematite. Less than one percent chlorite is present.

Pink granite fragments and metamorphic rock fragments are subangular to subround and are present only in the conglomerate. The metamorphic rock fragments consist of chlorite-illite-mica schist and gneiss.

The maximum measured thickness is 380 feet, but the total thickness is interpreted as being at least 400 feet.

The roundness, sorting, bedding characteristics, and textural immaturity of the conglomerate, sandstone, and siltstone indicate that they are alluvial fan type deposits. A wide range of weathering in the feldspar and the presence of a clay matrix are indicative of a humid climate during the deposition of the Blanco Basin formation.

The variety of minerals and rock types in the formation suggest that they were derived from multiple sources. The roundness, sorting, and textural immaturity indicate that the material was not transported far from its source. Outcrops of granitic and metamorphic rocks in the region north and east of the Chama quadrangle suggest it as the major source of the detritus of the Blanco Basin formation.

In the Chama quadrangle the Blanco Basin formation is separated from older rocks by a marked angular unconformity. This contact is slightly undulating and fragments of the older rocks are included within the formation. The Conejos quartz latite overlies the Blanco Basin formation.

The age of the Blanco Basin formation has been tentatively classified by the U.S. Geological Survey as Oligocene(?) (Cross and Larsen, 1935, p. 49). At the type locality it is overlain by the Conejos quartz latite of upper Miocene age and underlain by folded Cretaceous rocks. Cross and Larsen (1935, p. 49-50) correlated the Blanco Basin formation with the Telluride conglomerate because of the close lithologic and stratigraphic similarity of the two formations. Van Houten (1957) has proposed an upper Paleocene and lower Eocene age for the formation on evidence that the rocks underlying the Telluride conglomerate, which he correlated with the Blanco Basin formation, are lower Paleocene instead of Eocene. Van Houten further stated that the Blanco Basin and Telluride formations are probably course arkosic facies of the San Jose ("Wasatch") formation. Petrographic comparison by W. H. Harris (unpublished report, 1960) of samples from the lower Wasatch (of Dane, 1948) south of Dulce with Blanco Basin samples from the Chama quadrangle show that this is a possible correlation. Field mapping by Muehlberger in the Brazos Peak quadrangle demonstrated an interfingering of the Blanco Basin formation and the El Rito formation near the Canones box. South of the Canones box the basal Tertiary unit is the El Rito formation which consists of several hundred feet of well-cemented conglomerate composed of rounded cobbles of quartzite. (Correlation based on mapping by H. H. Doney in the Cebolla quadrangle and reconnaissance by Doney, C. T. Smith, and Muehlberger to the type locality.) No fossils have yet been found in the Blanco Basin formation so no definite age assignment can yet be made.

Conejos quartz latite. — The Conejos quartz latite is the basal formation of the Potosi volcanic series. The Potosi volcanic series was originally named the "Potosi Rhyolite series" by Cross and Purington (1899, p. 55), but Cross, **et al** (1905, p. 10) changed it to its present designation. This series, named for rocks exposed at Potosi Peak in the Silverton quadrangle, Colorado, is divided into six formations of which only the lower two are present in the Chama quadrangle, the Conejos quartz latite and the Treasure Mountain rhyolite.

The name Conejos formation was first published by Patton (1917, p. 20), the name having been supplied by Cross and Larsen. Cross and Larsen (1935, p. 72) used the term Conejos andesite, but they later changed it to Conejos quartz latite (Larsen and Cross, 1956). The Conejos was

named for a rock unit exposed along the Conejos River in south-central Colorado. According to Larsen and Cross (1956, p. 96-98), the Conejos consists of quartz latite tuff, breccia, agglomerate, flow breccia, sandstone, conglomerate, and flows. It is overlain by Treasure Mountain rhyolite. The Conejos is one of the most widespread volcanic formations of the San Juan Mountains and covers 10,000 square miles with an average thickness of 1,600 feet.

In the Chama quadrangle the Conejos crops out in the northeastern parts. The massive hard breccia and agglomerate, of which the upper portion consists, forms irregular-shaped prominent cliffs. The lower portion, which consists of tuff and conglomerate, is everywhere poorly exposed. Chromo Peak is held up by a volcanic rock and associated volcanic agglomerate of Conejos quartz latite.

The tuff of the lower unit is very light orange, aphanitic, and is largely altered to clay. Larsen and Cross (1956, p. 103) in describing similar rocks in another formation stated that the tuffs are partly alunitized, partly sericitized, partly altered to clay, and partly silicified. It is possible that the tuff of the Chama quadrangle is similar to those described by Larsen and Cross.

Subangular to well rounded fragments of granitic and metamorphic rocks make up the loosely consolidated conglomerate of the lower unit. The fragments range in size from sand to boulders with cobbles being the most common size. The maximum measured thickness of the conglomerate is 150 feet.

The roundness, sorting, and composition of the conglomerate indicates that it is a water-laid deposit derived from the erosion of Precambrian rocks. Larsen and Cross (1956, p. 98) include it within the Conejos with reservations. Southeast, in the Cebolla quadrangle, mapping by H. H. Doney has demonstrated a two-fold conglomerate unit with a lower dominantly of Precambrian and an upper of dominantly volcanic clasts. The upper unit correlates with the top member of the Los Pinos formation, which, in the Brazos Peak quadrangle lies unconformably across the Conejos and Treasure Mountain formations. The Brazos box region acted as a drainage divide during Potosi time so that correlations across it are uncertain. The Precambrian clast conglomerate in Doney's area may have been deposited throughout all of Potosi time. North of the Brazos box and east of Brazos Peak the Precambrian clast conglomerates interfinger with Conejos volcanic clast conglomerates and locally also with the Treasure Mountain volcanic clast conglomerates.

The upper unit of the Conejos consists of poorly sorted breccia and agglomerate. The fragments in these rocks consist chiefly of dark merocrystalline to holocrystalline porphyritic quartz latite, ranging in size from very fine-grained sand to cobbles. Some of the fragments, however, are as large as several feet across. The quartz latite contains from 5 to 20 percent phenocrysts. The phenocrysts consist of tabular plagioclase, biotite, hornblende, and pyroxene.

The thickness of the Conejos quartz latite as measured graphically is approximately 1,200 feet. Trice (1957, p. 18) found 1,500 feet of Conejos in the Los Pinos River canyon in the northeastern part of the Brazos Peak quadrangle.

Although the contact between the Conejos and the underlying Blanco Basin formation is not exposed in the Chama quadrangle, it is considered to be disconformable because of the drastic change in cementation and lithology. The Treasure Mountain rhyolite disconformably overlies the Conejos in the Chama quadrangle.

Treasure Mountain rhyolite. — The name Treasure Mountain formation was first published by Patton (1917, p. 20) and it, too, like the Conejos, was supplied to Patton by Larsen and Cross. The name was applied to rocks exposed on Treasure Mountain in northwestern Summitville quadrangle, Colorado. Cross and Larsen (1935, p. 76) renamed these rocks the Treasure Mountain quartz latite, but it was later changed to the Treasure Mountain rhyolite (Larsen and Cross, 1956, p. 63). According to Larsen and Cross (1956) "the Treasure Mountain is made up in most places of a series of alternating flows, welded tuffs, and tuff beds of rhyolite and rhyolitic quartz latite." At Treasure Mountain, Colorado, the Treasure Mountain rhyolite is underlain by the Conejos quartz latite and is not overlain by the younger formations.

The Treasure Mountain rhyolite outcrops east of the Chama quadrangle and is included here because it forms the skyline rim visible from U.S. 84 near Chama (in particular Slide Rock Point). The upper part of the formation is well exposed and forms cuestas and mesas whereas the lower part of the formation is generally mantled by talus and landslide debris.

Trice (1957) subdivided the Treasure Mountain rhyolite in the northeastern part of the Brazos Peak quadrangle into three members; in ascending order they are: the Toltec andesite, Lagunitas clastic member, and Osier Mountain welded tuff. The upper two members crop out in the Chama area. The Toltec andesite does not crop out in the Chama area, but its presence is revealed by float at the base of Slide Rock Point. The indentifications used in this report are from Trice (1957).

The Toltec andesite member consists chiefly of black, perlitic, vitric, porphyritic andesite (an ignimbrite) that contains phenocrysts of tabular plagioclase and abundant inclusions of volcanic rock fragments. Pale-brown, vesicular, porphyritic-aphanitic andesite containing abundant inclusions of pale-brown, scoriaceous, aphanitic volcanic rock overlies the basal ignimbrite and it may be capped by another black andesite identical with the basal ignimbrite. This member fills valleys cut into the underlying Conejos quartz latite and ranges in thickness from 0 to 50 feet.

The Lagunitas clastic member consists of interbedded and parallel bedded volcanic sandstone, volcanic conglomerate, tuffaceous mudstone, and tuffaceous breccia. A loosely consolidated volcanic sandstone is the most abundant rock type in the Lagunitas clastic member. The particles of the sandstone range in size from very fine-grained sand to pebbles, are poorly sorted, and consist chiefly of dark asphanitic volcanic rock. Volcanic conglomerate occurs as channel fillings within the sandstone.

Tuffaceous mudstone is present in large amounts. The mudstone varies from white to gray to pink, and, as the name implies, it consists predominantly of clay-and-silt size particles. About 3 to 5 percent of the mudstone consists of sand-size particles composed of quartz, feldspar, biotite, hornblende, and volcanic rock fragments. Many of the volcanic rock fragments and finer grained particles have been altered to bentonite.

Lithic tuffaceous breccia is very similar to the tuffaceous mudstone except for the difference in size and a greater amount of volcanic rock fragments. The volcanic rock fragments as well as the clay-and-silt sized particles have been altered to bentonite.

The Lagunitas clastic member is 232 feet thick at Slide Rock Point.

The bedding, sorting, and roundness of the Lagunitas clastic member suggest that it was in part fluviatile in origin and in part eolian. The fluviatile materials were deposited by rivers or smaller streams, but they, in part, may have been deposited in lakes. Part of the material was probably derived from older volcanic rocks, but much of it was probably derived from pyroclastic eruptions.

The Osier Mountain welded tuff member of the Treasure Mountain rhyolite is a rhyolite near quartz latite in composition. The welded tuff weathers into slabby fragments parallel to the top of the bed. It is light gray to medium light gray at the top, and grades to pale red at the base. It is merocrystalline and porphyritic-glassy. The amount of phenocrysts range from 5 to 20 percent of the rock. The phenocrysts are tabular plagioclase, flakes of biotite, and stubby prisms of green pyroxene. The upper part of the member is characterized by yellow bentonitic amygdules. The groundmass consists of glass dust and shards which have been partly altered to bentonite. The welded tuff is of pyroclastic origin and is probably the result of a **nuee ardente** type of eruption (Trice, 1957).

The Osier Mountain welded tuff member at Slide Rock Point is 54 feet thick.

The age of the Potosi volcanic series is considered by Knowlton (1923, p. 184) to be Miocene, probably upper Miocene. Brown (Larsen and Cross, 1956, p. 260) considered the Creede formation which overlies the Potosi volcanic series in southern Colorado to be late Miocene or perhaps early Pliocene. Unconformably overlying the Treasure Mountain rhyolite 10 miles east of the Chama quadrangle is the Los Pinos gravel the uppermost member of which Butler (1946) found correlative in part with the lower portion of the Santa Fe formation. The Santa Fe is late Miocene to early Pliocene (Wright, 1946, p. 413). Butler stated that the Los Pinos is probably late Miocene. Because of the lack of independent information concerning the age of the Conejos and Treasure Mountain formations in the Brazos Peak and Chama quadrangles, they are considered to be late Miocene on the basis of the references cited above.

QUATERNARY SYSTEM

Working in Colorado and northern New Mexico, Atwood and Mather (1912, p. 387) found evidence for 3 stages of glaciation in the San Juan Mountains. The currently accepted terms used in classifying these glacial deposits are those used by Atwood and Mather in 1932 and are from oldest to youngest: Cerro, Durango, and Wisconsin. Representatives of each of these glacial stages are present in the Chama quadrangle. River terrace deposits, kame terrace deposits, and landslide deposits that can be correlated with the glacial materials are described at the appropriate places in the road logs of this guidebook.

Cerro kame terrace and terrace deposits are more than 200 feet above present stream levels along the Rio Chamita and the Continental Divide north of U.S. 84. Durango deposits lie between 100-200 feet above present stream levels. Wisconsin deposits are mostly within 50 feet of the present stream levels.

Gravel caps, 400 and more feet above stream level, such as on Rabbit Peak (800 feet ±) and El Cerro dome (500 feet), are believed to be pre-Cerro glaciation and may be equivalent to either the Los Pinos gravels or Hinsdale formation of the southern San Juan Mountains.

Extensive landslide masses obscure the bedrock features over large areas in the quadrangle. Those areas underlain by the Mancos formation are most susceptible to mass movement. The high country north and west of Chama have undergone such extensive sliding that accurate interpretation of the underlying stratigraphy and structure is virtually impossible from the available surface data.

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Table 1.—Summary of Exposed Paleozoic and Mesozoic Stratigraphic Units in Chama quadrangle and vicinity, New Mexico

System	Stratigraphic Unit	Thickness (feet)	Lithology
		TOP NOT EXPOSED	
Cretaceous	Lewis formation	600+	Fissile, dark-gray shale
	Mesaverde group undivided	218-262	Massive, yellowish-gray to dark-orange, fine- to very fine-grained sandstone with shale and sandy shale intercalations. Coal absent in Chromo Peak region.
	Mancos formation Upper Mancos undifferentiated (included Niobrara calcareous shale and Upper shale members of Dane, 1948)	1100+	Dark-gray shale, weathering light-gray. **Ostrea congesta** and **Inoceramus grandis** prisms common in lower part; silty in upper part. Thin, yellow-buff, calcareous sandstone layer near base.
	Carlile shale member	435±	Fissile, yellowish-gray or light brownish-gray mudstone and claystone. Thin siltstones, septarian concretions, and limestone in middle part.
	Greenhorn limestone member	12-20	Whitish-gray limestone interbedded with dark gray shale.
	Graneros shale member	100-150	Dark-gray shale. Yellow-weathering calcareous concretions in the upper part.
	Dakota formation	230-390	Pale-orange sandstone units alternating with dark-gray shale and siltstone. Crossbedded and conglomeratic in basal units. Other sandstones parallel bedded or cross-bedded.
		DISCONFORMITY	
Jurassic	Morrison formation	425±	Variegated grayish-green and pale-red mudstone interbedded with grayish-green to light-gray, fine-grained calcareous sandstone in the lower part.
	Wanakah formation		Generally covered.
	Todilto formation	20±	Upper Chavez Creek has an exposure of thin-bedded dark, bituminous crinkly-bedded, fetid limestone. Gypsum present as pebbles in sandstones. Both units mapped as part of Morrison formation.
	Entrada sandstone	250-300	Upper 100 feet is a grayish-orange, medium-grained, massive, parallel-bedded slightly friable sandstone. Lower 200 feet is a grayish-yellow, fine-to medium-grained, festoon crossbedded, friable sandstone.
Triassic	Chinle formation	450-500	Poorly exposed, pale-red arkosic siltstone and sandstone. Sandstones commonly crossbedded. Some cherts and calcareous zones. Conglomeratic sandstone composed of Precambrian quartzite detritus at base. Conglomeratic sandstone in middle of unit.
		ANGULAR UNCONFORMITY	
Pennsylvanian	Unnamed unit	350±	Sandstone and silstone, 200±, with a basal talus, disconformably underlying an arkosic sandstone that is capped by a nodular limestone containing Des Moinesian marine fossils. Top 150 covered.
		ANGULAR UNCONFORMITY	
Precambrian	Kiawa Mountain formation	5,000-10,000	Medium- to coarse-grained, massive crossbedded metaquartzite with pebbly beds.