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GEOLOGY AND URANIUM POTENTIAL OF THE TEJANA MESA-HUBBELL DRAW AREA, CATRON COUNTY, NEW MEXICO

By

David R. Guilinger

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ABSTRACT

Exposures within the Tejana Mesa-Hubbell Draw (TM-HD) area of west-central New Mexico (Catron County) represent Late Cretaceous and Cenozoic continental sedimentation and late Cenozoic basaltic volcanism, punctuated by periods of weathering and erosion. The TM-HD area is located at the southern margin of the Colorado Plateau and along the northern eroded margin of the Datil-Mogollon volcanic field.

The Mesaverde Group (Late Cretaceous) is the oldest unit of the TM-HD area and consists of drab-colored (yellowish brown and gray), carbon-rich coastal plain deposits. The Mesaverde Group is unconformably overlain by fluvial, intermontane basin deposits of the Baca Formation (Eocene) which are in turn conformably overlain by volcanic wackes and claystones of the early Oligocene Spears Formation (basal unit of the Datil-Mogollon volcanic field). In early Miocene time, Oligocene and older rocks were tilted gently to the southeast (one to three degrees dip), beveled by erosion, and then buried by volcanic-rich alluvial sediments (Fence Lake Formation) shed northwestward off of the volcanic highlands of the Datil-Mogollon field. Basaltic lavas, which now cap high mesas, were erupted onto the alluvial apron from a northeast-trending fault zone (element of Jemez lineament?) which transects the TM-HD area.

An anomalous color zone of reddish sandstones and purplish mudstones was found to be stratigraphically situated within the top portion of the normally drab-colored rocks of the Mesaverde Group. This color zone is interpreted to be an oxidation zone formed in the lower

portion of a lateritic weathering profile that was developed on the Mesaverde Group prior to deposition of the Baca Formation. In the subsurface, the bulk of the Mesaverde Group is chemically reduced in character (carbon rich, $FeS2$ common). Outcrop weathering of typical Mesaverde rocks produces drab yellowish brown oxidation colors indicative of hydrated $Fe2O3$ (goethite). The rocks of the oxidation zone, however, represent the basal remnant of a paleoweathering profile that is revealed, by present day weathering, as reddish and purplish oxidation colors indicative of nonhydrated $Fe2O3$ (hematite). The epigenetic nature of the oxidation zone is demonstrated by its basal redox boundary which generally parallels sandstone-mudstone contacts, but also locally cuts across bedding in the form of "C"-shaped alteration fronts (similar in geometry to Wyoming-type uranium roll fronts).

A clay mineral analysis of mudstones from the Mesaverde Group and the oxidation zone indicate high kaolin contents (a weathering index) in both, but no obvious enrichment of kaolin in the oxidized zone. Kaolin enrichment typically occurs in the upper portions of tropical weathering profiles. Vertical variations in the kaolin content of the oxidized zone probably reflect the primary mineralogy of the clay sediments and diagenesis of these sediments prior to the development of the pre-Baca weathering profile. These observations are consistent with the interpretation of the color zone as the basal or "C" horizon of a tropical paleosol where only minor alteration effects such as oxidation occur.

A cluster of seven radiometric anomalies and one small uranium deposit (production, 5lbs U3O8) are closely associated with the redox boundary at the base of the oxidation zone. Oxidizing and acidic soil waters, produced by tropical weathering, presumably leached uranium from slightly uraniferous mudstones (carbonaceous) of the Mesaverde Group and concentrated the uranium at a widespread redox boundary that formed below the paleowater table. The pre-Baca oxidation zone is therefore considered to be the primary zone of uranium potential in the TM-HD area.

The sandstones of the Baca Formation are another potential host for uranium deposits. Uranium for such possible deposits could have been provided by erosion of the lateritic soil from uplifts and basin margins that flushed uranium-rich waters into the Baca Basin. The Baca sandstones are good aquifers. A bleached appearance of most of the sandstones suggests that they may be chemically reduced in the subsurface and therefore may have the capacity to contain uranium deposits.

In the Datil Mountains, "C"-shaped alteration fronts exposed at the base of the pre-Baca weathering profile are commonly radioactive, verified as uranium bearing, and sharply defined by greenish-gray chlorite bands (Chamberlin, 1981). These characteristics, interpreted as features of leached uranium roll fronts, have not been observed in "C"-shaped redox fronts at the base of the pre-Baca oxidation zone in the TM-HD area. Until reasons for this difference can be explained, it will be presumed that the probability for discovery of uranium-roll-front deposits in the subsurface of the TM-HD area is less than that of the Datil Mountains area.

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INTRODUCTION

Problem and Purpose

Numerous uranium occurrences are located near the contact between Cretaceous-Tertiary age rocks, along the southern margin of the Colorado Plateau, in west-central New Mexico (Griggs, 1954). A number of of these occurrences are in the Datil Mountains area and some (eg. the Red Basin deposits and the McPhaul adit deposit; Bachman and others, 1957) are spatially associated with the base of a zone of oxidized Cretaceous rocks (Mesaverde Group) that immediately underlies the Eocene Baca Formation (Chamberlin, 1981). Two uranium occurrences are reported in the present study area near Quemado. One of these, the Mangum prospect, is reported in Hilpert (1969) to be located in the Mesaverde Group. The other occurrence is the Varnum deposit and it is reported in Hilpert (1969) to be in the Mesaverde Group and by May and others (1980) to be in the Baca Formation. This discrepency points to a fundamental stratigraphic problem in recognizing the actual host rock for the uranium occurrences.

The purpose of this thesis is to present the results of detailed geologic mapping of the Tejana Mesa-Hubbell Draw (TM-HD) area, Catron County, New Mexico. This will clarify the stratigraphic position of the uranium occurrences and provide the stratigraphic and structural framework to evaluate the uranium potential of the TM-HD area. An anomalous color zone of reddish sandstones and purplish mudstones within the uppermost Mesaverde Group, which normally consists of drab colored sandstones and mudstones, was found to be stratigraphically situated immediately below a regional unconformity at the base of the Baca Formation. The character of this oxidized zone is compared to that of a similar zone in the Datil Mountains area, which is interpreted by Chamberlin (1981) to be part of a paleo-weathering profile. Determination of the nature of the oxidized zone, and its relationship to the uranium occurrences and radiometric anomalies in the region, will facilitate the study of the uranium potential of the TM-HD area.

Location and Accessibility

The TM-HD area is located approximately nine miles north of Quemado, New Mexico in Catron County (fig. 1). It encompasses an area of about 60 square miles and is situated on private, public, and state lands that are owned or controlled by numerous ranches in the region. Map boundaries were chosen so as to maximize coverage of the contact between the Mesaverde Group and the Baca Formation. The map area includes portions of the U.S. Geological Survey Tejana Mesa, Mariano Springs, and Techado 7.5 minute topographic quadrangles (fig. 2). The approximate center of the TM-HD area is lat 34 29´20´´ N., long 108 28´40´´ W.

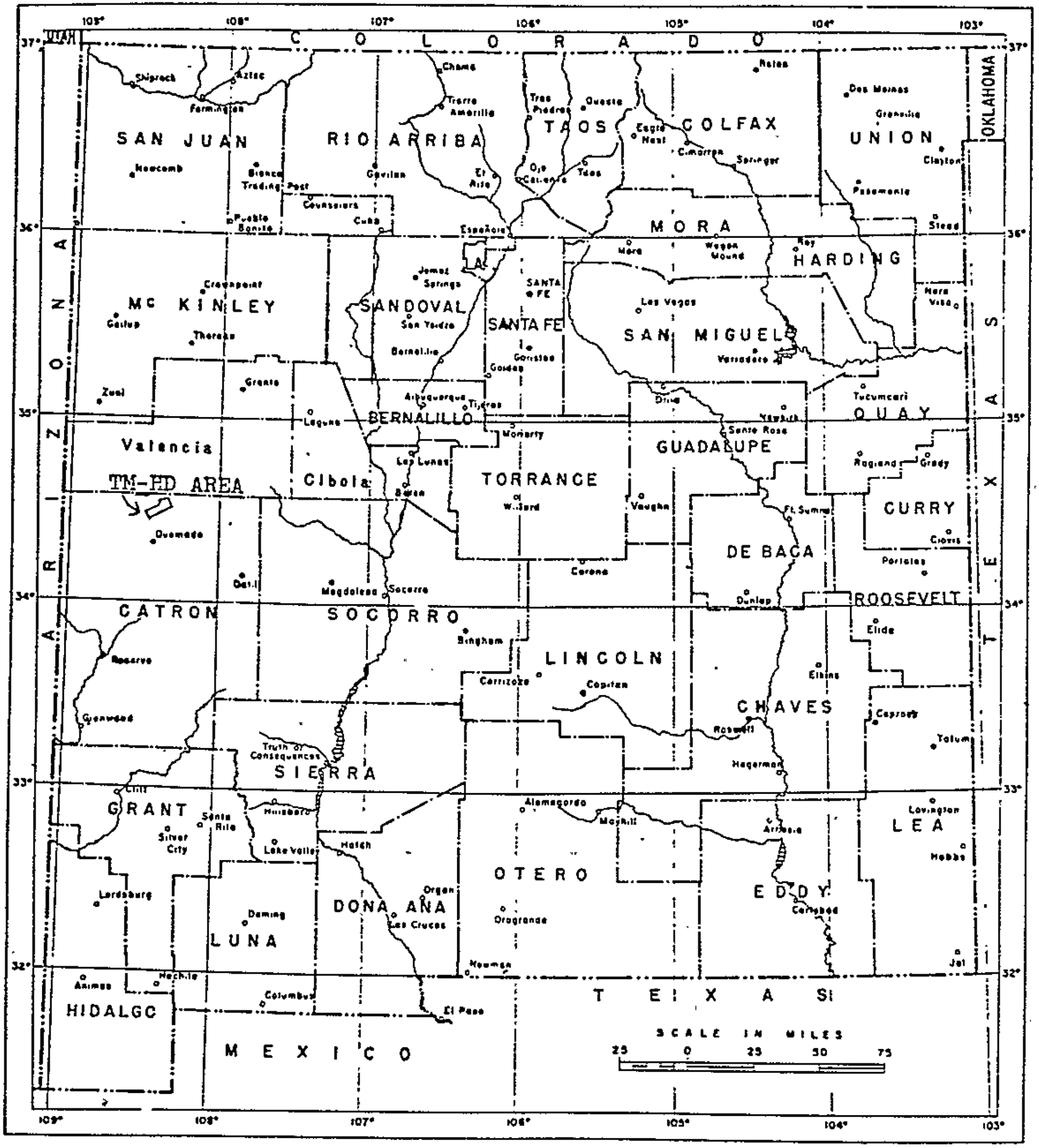

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Figure 1. Index map of New Mexico, showing the location of the Tejana Mesa-Hubbell Draw (TM-HD) area.

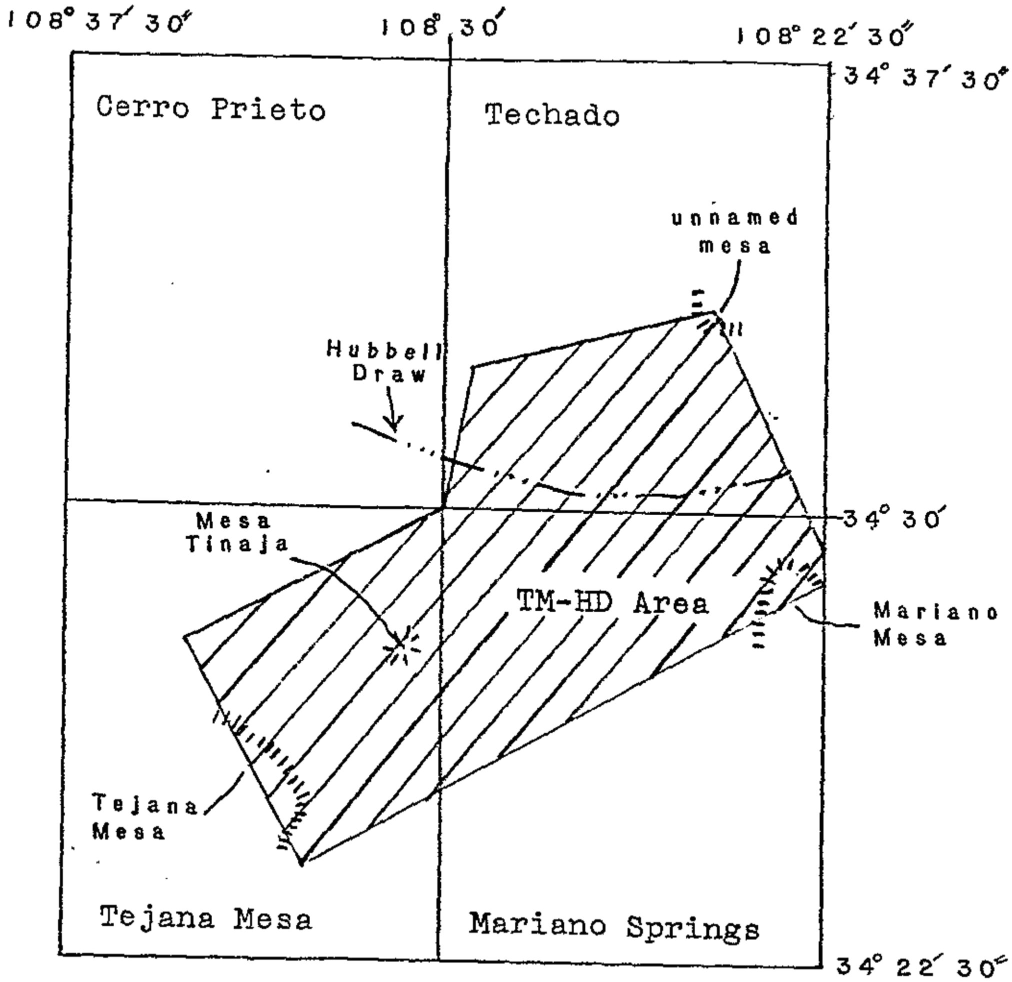

Figure 2. Location of the TM-HD areawithin the Tejana Mesa, Mariano Springs, and Techado 7.5 minute topographic quadrangles (U.S. Geological Survey).

Access to the eastern half of the study area is provided by New Mexico State Highway 117 and the connecting Hubbell-Ranch road. The western half is reached by taking the Mangum-Ranch road either north from U.S. Highway 60 at Quemado, or south from its connection with the Hubbell-Ranch road. Numerous improved and unimproved roads criss-cross the area and provide access to within about a mile and a half of any point in the study area. A four-wheel drive vehicle is required in wet weather.

Methods of Investigation

Detailed geologic mapping was carried out at a scale of 1:24,000 on parts of the U.S. Geological Survey Tejana Mesa, Mariano Springs, and Techado 7.5 minute topographic quadrangles (fig. 2). Color aerial photographs (Bureau of Land Management series "NM-2") were particularly helpful in delineating the distinctly colored map units. The photos were also useful in locating outcrops and mapping alluvium and colluvium deposits. A scintillometer was carried during field mapping to locate radiometric anomalies.

Thin-sections were analyzed to determine the petrographic characteristics of each rock unit mapped and to characterize the alteration of the anomalous color zone. Rock coloration is an important criterion in the distinction of altered (oxidized) and unaltered (generally of reduced character) Mesaverde rocks. Whenever possible, rock colors area), Chamberlin (1981) recognized that uranium deposits in the Red Basin area (Gulf Minerals property) occur at the base of a pre-Baca weathering profile (paleosol) which was developed on Cretaceous rocks equivalent to the Mesaverde Group.

Previous mapping at a reconnaissance level (1:126,720), which covered portions of the TM-HD area, included the Canyon Largo 30 minute quadrangle (Willard and Weber, 1958) and the Pinonville 30 minute quadrangle (Willard, 1957). Campbell (1982) has mapped the Cerro Prieto 7.5-minute quadrangle, located just north of the Tejana Mesa quadrangle, as part of a cooperative coal-resource evaluation of the Salt Lake field by the U.S. Geological Survey and the New Mexico Bureau of Mines and Mineral Resources. Also, as a part of this continuing evaluation, F. Campbell is currently mapping the Techado quadrangle and G. H. Roybal is mapping the Tejana Mesa quadrangle.

A list of the rock-stratigraphic units mapped in the TM-HD area is presented in Table 1, along with references of previous work most pertinent to the geology of the study area.

were described with the use of the Geological Society of America, rock-color chart (Goddard and others, 1979). All color terms taken from this chart are followed in parentheses by the appropriate number-letter code.

The clay mineralogy of 13 mudstone and claystone samples was determined by X-ray diffraction to evaluate a "weathering profile" hypothesis for the zone of oxidized Cretaceous rocks. A sample from a carbonaceous mudstone, preserved within the oxidized zone, was collected for pollen and spore analysis to determine the age and environment of deposition of the rocks within the oxidized zone. Paleocurrent directions were determined for the Mesaverde Group and the Baca Formation by measuring the direction of axis plunge of trough cross-stratification, the direction of maximum foreset inclination of planar cross-stratification, and the strike of parting lineations. Methods of petrographic, clay, and paleocurrent analysis are described in appendices A, B, and C, respectively.

Previous Work

The two known uranium occurrences in the TM-HD area, the Varnum deposit and the Mangum prospect, were first reported in Hilpert (1969) and were said to occur in the Mesaverde Group. May and others (1980) discuss the Varnum deposit and stated that it is found in the Baca Formation. In his evaluation of the uranium potential of the Datil Mountains-Pietown area (20 miles southeast of the TM-HD

Table 1. Rock-stratigraphic units of the TM-HD area and pertinent references.

Rock-stratigraphic units	References
Mesaverde Group:	*Holmes (1877), Gadway (1959), Foster (1964) Molenaar (1973), Molenaar (1977).
Baca Formation:	*Wilpolt and others (1946), Tonking (1957), Willard (1959), Potter (1970), Snyder (1971), Johnson (1978), Massingill (1979), Cather (1980), Chamberlin (1981).
Spears Formation:	*Tonking (1957), Willard (1959), Chapin (1971), Harrison (1980), Chamberlin (1981).
Fence Lake Formation:	*McClellan and others (in prep.), Campbell (1982).
Bidahochi(?) Formation:	*Reagan (1924), Repenning and Irwin (1954), Repenning and others (1958).

*named formation or group

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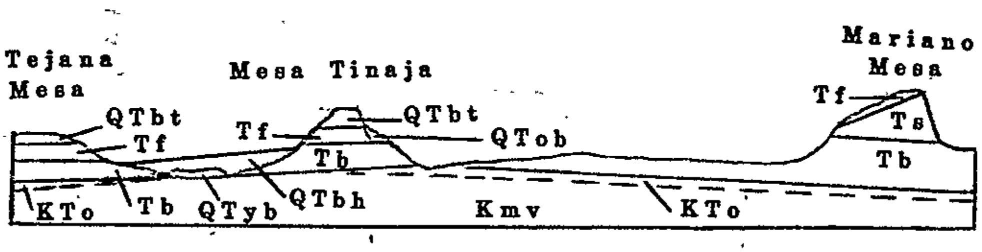
STRATIGRAPHY AND PETROLOGY

The Tejana Mesa-Hubbell Draw area of Catron County, New Mexico is comprised of Cretaceous, Tertiary, and Quaternary rocks that include sedimentary and volcanic units. The sedimentary rocks are composed of sandstones, siltstones conglomerates, mudstones, claystones, shales, and volcanic wackes. The extrusive rocks are porphyritic olivine-augite basalts with minor amounts of associated flow breccia and basaltic pyroclastics. The sedimentary and volcanic sequences were divided into eight mappable units. From oldest to youngest they are: the Mesaverde Group, the Baca Formation, the Spears Formation, the Fence Lake Formation, the "Basalt of Tejana Mesa", older Quaternary-Tertiary basalt, the Bidahochi(?) Formation, and younger Quaternary-Tertiary basalt (interbedded in the Bidahochi(?) Formation). In addition, a Cretaceous-Tertiary oxidation zone, developed on the upper portion of the Mesaverde Group, was mapped as a soil-stratigraphic unit.

The spatial relationships of map units are displayed on a diagrammatic cross-section (fig. 3) that transects the TM-HD area from Tejana Mesa, to Mesa Tinaja, to Mariano Mesa. The cross-section illustrates three major unconformities at the base of the Baca Formation, at the base of the Fence Lake Formation, and at the base of the Bidahochi(?) Formation. The Bidahochi(?) Formation is distinctly inset into the older strata.

Figure 3. Diagrammatic cross-section of the Tejana Mesa-Hubbell Draw area showing stratigraphic relationships of the map units along with lithologic descriptions of the map units.



Descriptions
(oldest to youngest)

Kmv	Mesaverde Group (Late Cretaceous): (greater than 500 ft) sandstones, siltstones, mudstones, claystones, and shales: sandstones are grayish-yellow (5Y 8/4) speckled with white, fine to medium grained, moderately sorted, friable, and poorly cemented with silica and/or calcite cement; sandstones are lenticular with thicknesses ranging from 5-35 feet, medium to large scale trough cross-stratification common; siltstones are pale-yellowish-brown (10 YR 6/2) to moderate-brown (5YR 4/4), well-indurated, and cemented with calcite cement; medium-scale planar cross-stratification common; mudstones, claystones, and shales are generally pale-olive (10YR 6/2) to light-gray (N7) with a few black carbonaceous mudstone units.
KTo	Post-Mesaverde, pre-Baca Oxidation Zone (Paleocene ? paleosol of Chamberlin, 1981): (0-160 ft) oxidation zone developed on uppermost Mesaverde Group; light- to brick-red sandstones common near base of zone, sandstones in upper portion of zone are light-red to grayish-yellow (5Y 8/4); mudstones, claystones and shales are commonly pale-reddish-purple (5 RP 6/2) or light-gray (N7), contains a few black carbonaceous (unoxidized) mudstones; lower color (redox) contact usually follows sandstone-mudstone contacts, but locally cuts sandstone beds at high angles.
Tb	Baca Formation (Eocene): (25-600 ft) sandstones, mudstones, and conglomerates: sandstones are dominantly pale-yellowish-orange (10 YR 8/6), fine to coarse-grained, poorly sorted, with calcite and/or silica cement; medium-scale trough cross-stratification common; mudstones are dark-reddish-maroon; conglomerates are both clast and matrix supported; clast lithologies include quartzite, milky quartz, jasper, silicified wood, and sandstone; lower contact is a low-relief, erosional unconformity with the Mesaverde Group.

Ts	Spears Formation (early Oligocene): (20-520 ft) volcanic wackes and claystones: volcanic wackes are light gray (N7), very poorly sorted, and calcareous; claystones are pale-red (10 R 6/2); both lithologies contain widely scattered granule to cobble-sized clasts of hornblende-plagioclase rhyodacite/latite porphyry; lower contact is gradational with the Baca Formation.
Tf	Fence Lake Formation (mostly Miocene): (180 ft) sandstones and conglomerates: sandstones are very-light-gray (N8) to pinkish-gray (5 YR 8/1), fine- to coarse grained; boulder conglomerates occupy the lower (0-50 ft) portion of the unit; clasts are dominantly basalt with decreasing amounts of rhyodacite, rhyolite, chert, sandstone, and quartzite; lower contact is an angular unconformity and moderate relief disconformity with the Baca Formation and the Spears Formation.
QTbt	Basalt of Tejana Mesa (late Miocene ?-Pliocene ?): (0-360 ft) olivine-augite basalts, porphyritic with phenocrysts of olivine and pyroxene, contain rare mafic xenoliths, interlayered with black and reddish-brown scoria units; basalts rest upon a sedimentary-pyroclastic transition zone that overlies the Fence Lake Formation, transition zone is 10-25 ft thick and consists of scoria-rich sandstones and conglomerates that grade upward into bedded scoria.
QTob	Older Quaternary-Tertiary basalts (Pliocene ?-Pleistocene ?): (0-60 ft)olivine basalts, porphyritic with phenocrysts of olivine and pyroxene, contains rare mafic xenoliths, relationship to QTbt uncertain, lower contact is an erosional unconformity with the Fence Lake and Baca formations.
QTbh	Bidahochi(?) Formation (Pliocene ?-Pleistocene ?): (0-280 ft) sandstones, conglomeratic sandstones, conglomerates, minor mudstone, claystone, sandy limestone and bedded scoria; sandstones are light-gray (N7) to pinkish-gray (5 YR 8/1), fine to coarse grained, poorly sorted, and calcareous; conglomerates and conglomeratic sandstones contain clasts like those in the Fence Lake Formation plus a greater abundance of scoria, sandstone, and sandy limestone; cut-and-fill channels common; claystones are dark-reddish-maroon; limestones consist of sand grains floating in white calcite; lenticular scoria beds are as much as two feet thick and cemented with calcite, the Bidahochi(?) Formation occupies a paleovalley that cuts through the Fence Lake Formation and Baca Formation and into the Mesaverde Group.
QTyb	Younger Quaternary-Tertiary basalts (Pliocene ?-Pleistocene ?): (0-30 ft) olivine-augite basalt, porphyritic with phenocrysts of olivine and pyroxene, contain rare mafic xenoliths; petrographically indistinguishable from QTbt or QTob flows, interbedded in the base of the Bidahochi(?) Formation.

Late Cretaceous Rocks

Mesaverde Group

The name Mesa Verde Formation was proposed by Holmes (1877) for a sequence of sandstones and coal units that cap Mesa Verde in southwestern Colorado. In the vicinity of its type section, the Mesa Verde Formation is 1000 to 1200 feet thick and conformably overlies a 2000 foot thick section of Mancos Shale (Collier, 1919). The name "Mesaverde Group" was later substituted for the Mesaverde Formation throughout the San Juan Basin (Beaumont and others, 1956). Molenaar (1977) stated that the use of the name Mesaverde, outside of its type area, "...has lost much of its meaning, except that it refers to the thick marine and nonmarine unit overlying the main thick Upper Cretaceous shale". The Lewis Shale (marine) conformably overlies the Mesaverde Group. The age of the Mesaverde Group is Late Cretaceous (Molenaar, 1977).

In the San Juan Basin area, the Mesaverde Group and the Mancos Shale record a history of four or five major transgressive/regressive cycles and numerous minor cycles. Clastic sediments were supplied to the San Juan Basin from the southwest (Molenaar, 1977). South and southwest of the San Juan Basin, in the vicinity of the TM-HD area, the Mesaverde Group is comprised of the Crevasse Canyon Formation and the underlying Gallup Sandstone (Molenaar, 1973). These units represent the beginning of Mesaverde deposition at the expense of (contemporaneous with) the

Mancos Shale, which underwent uninterrupted sedimentation in the northern part of the San Juan Basin (Sears, 1925; Molenaar, 1977). This relationship is demonstrated by the presence of about 500 feet of Mancos Shale in the Zuni Basin, located southwest of the San Juan Basin, and by a thickness of over 2000 feet of Mancos Shale in the northern portion of the San Juan Basin (Molenaar, 1977).

The Mesaverde Group of the TM-HD area consists of interbedded sandstones, siltstones, mudstones, claystones, and shales. The uppermost portion of the Mesaverde Group has been subjected to pre-Baca oxidation. Therefore, a description of the rocks of the oxidation zone will be included in this section. When it is necessary to distinguish between them, the rocks of the oxidized zone will be referred to as "altered", and the Mesaverde Group below this zone will be referred to as "unaltered". A maximum of 500 feet of altered and unaltered Mesaverde Group is exposed in the TM-HD area.

The weathered outcrop colors of unaltered Mesaverde sandstones are grayish yellow (5Y 8/4; see pg. 5) speckled with white. Fresh outcrop sandstone colors are pale yellowish orange (10YR 8/6) speckled with white. Most sandstones are friable. Minor amounts of very well indurated sandstones and siltstones, weathering to a pale yellowish brown (10YR 6/2) and moderate brown (5YR 4/4), are found throughout both the altered and unaltered Mesaverde rocks. These units are light gray (N7) and moderate yellowish brown (10YR 5/4) on a freshly broken surface. Unaltered mudstone, claystone, and shale colors consist of dusky yellow (5Y 6/4), light olive gray (5Y 5/2), pale olive (10Y 6/2), light gray (N7), and black. Subsurface colors of light gray (N7) to medium gray (N5) for both sandstones and shales of the Mesaverde were reported by Foster (1964) from a drill hole located approximately two miles south of the TM-HD area.

The two differently colored sandstones mentioned above are characteristic of the two general types of sandstone in the unaltered Mesaverde Group. The yellowish-orange, friable sandstones are usually trough cross-stratified with medium and large-scale troughs (McKee and Weir size classification, 1963). These sandstones vary from 5 to 35 feet in thickness and are lenticular. In thin-section, one of these sandstones (TM-212) is a fine to medium-grained, moderately sorted, lithic arkose (McBride classification, 1963) that is poorly cemented with dominantly silica cement and minor calcite cement. Lithic fragments, in thin-section, are dominantly granitic (quartz/feldspar fragments) with traces of andesitic lavas also present. A few pyrite grains are also present. Grayish clay chips and black carbonized twigs and plant debris are common in the unaltered sandstones.

Tabular zones of well cemented (calcite), brownish colored sandstones are common within or capping less indurated yellowish and grayish sandstones. The well indurated zones commonly exhibit planar cross-stratification. Cementation often parallels bedding and also cuts across bedding. The calcareous zones are found as both lenticular bodies, usually from two to five feet thick, and as spotty occurrences throughout the more abundant, friable sandstones (fig. 4). They are also often in the form of subspherical concretions (fig. 5). Petrographically they differ from the friable sandstones in that they are composed of loosely packed, very-fine-sand to silt-sized grains pervasively cemented with dominantly calcite cement and minor silica cement.

Approximately 40 percent of the Mesaverde of the TM-HD area is comprised of mudstone with minor amounts of claystone and rare shale. The mudstones range in thickness from 1 to 30 feet. The clay mineralogy of five unaltered mudstone samples (determined by X-ray diffraction, see appendix B) are presented in Table 2. Smectite, kaolinite, and illite were the only clay minerals detected. Smectite dominated the clay suite in three of the samples and was found in subequal amounts to kaolinite in two samples. Illite occurred in either trace or very minor amounts in the samples. All of the mudstones analyzed were noncarbonaceous and noncalcareous. Black carbonaceous mudstones are found in minor amounts in both the altered and the unaltered

Table 2. Clay Mineralogy of unaltered Mesaverde mudstones. (See appendix B for sample locations and analytical techniques.)

Sample No.	Clay Mineralogy (parts per ten)		
	Smectite	Kaolinite	Illite
TM 194	10	trace	trace
TM 211	10	trace	trace
TM 240	5	4	1
TM 243	8	2	trace
TM 244	5	5	trace

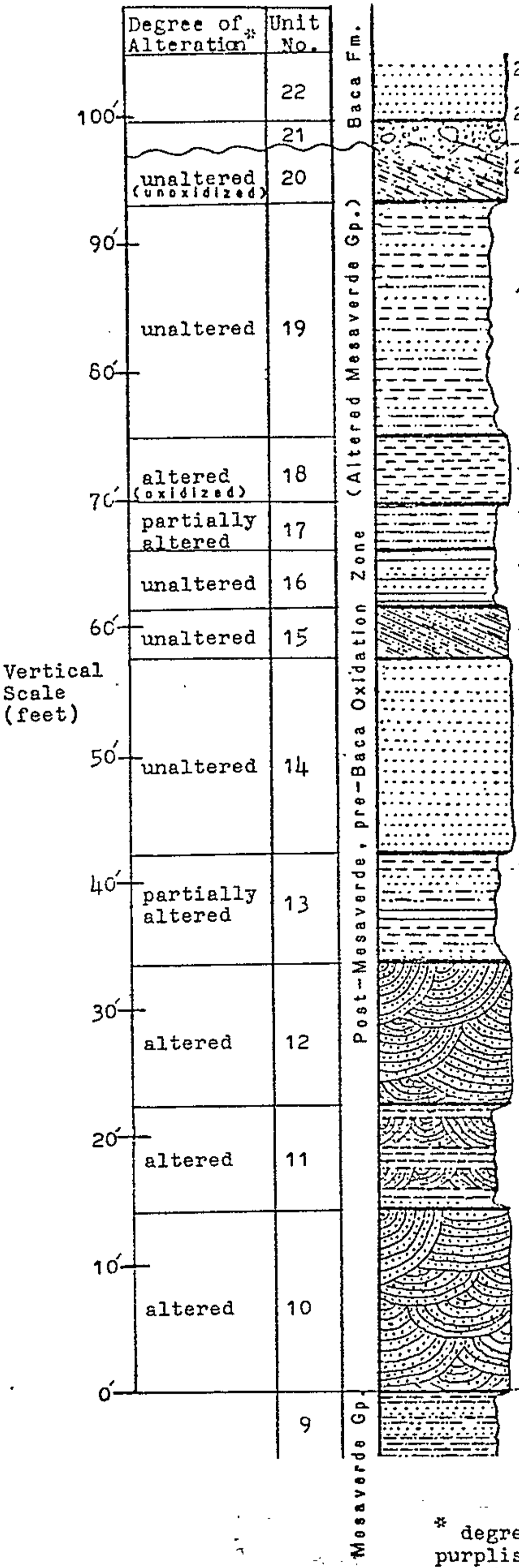
Figure 4. Tabular zones of well-indurated calcareous sandstones (brownish gray) within relatively friable sandstones (pale yellowish gray) of the Mesaverde Group (NW1/4 SW1/4 SE1/4 sec. 20, T.3N., R.16W.).

Figure 5. Gray calcareous sandstone concretions within Mesaverde sandstones (NW1/4 SW1/4 SE1/4 sec. 20, T.3N., R.16W.). Note the silicified log below the clipboard.

Mesaverde Group. A few silicified logs are found in the mudstones and sandstones of both the altered and unaltered units (fig. 5).

A stratigraphic section of the pre-Baca oxidation zone in the upper Mesaverde Group was measured north of Mesa Tinaja (NE1/4 SE1/4, sec. 16, and NW1/4 SW1/4 sec. 15, T.3N., R.16W). This section, summarized in figure 6, is indicative of the vertical distribution of lithologies (except for color) throughout both the altered and unaltered Mesaverde Group. Sandstone or mudstone intervals greater than about 35 feet thick are not present in the TM-HD area. The measured section of altered rocks consists of 64% sandstone and siltstone and 36% mudstone, claystone, and shale. Individual sandstone beds are nongraded and poorly bedded. Both the friable and well indurated sandstones and siltstones are ledge formers.

Paleocurrent direction measurements were taken on altered and unaltered rocks of the Mesaverde Group. Current indicators used were parting lineations, trough cross-stratification, and planar cross-stratification. These data are presented on separate rose diagrams (fig. 7) and in tabular form in appendix C. A generally north-northeasterly paleocurrent direction is indicated.



DESCRIPTIONS

22-sandstone, moderate-pink(5 R 7/4), medium-grained, very poorly sorted, calcite cement

21-conglomerate, pebble to boulder-sized clasts of mostly friable and well-indurated sandstone

20-siltstone, pale-yellowish-brown(10 YR 6/2), poorly sorted, well-indurated, calcareous, mottled with black patches of iron oxide cement, planar cross-stratification

19-mudstone and claystone, dominantly moderate-yellowish-brown(10YR 5/4) interlayered with dark-yellowish-orange(10YR 8/6); minor interbedded dark-yellowish-orange(10YR 8/6), fine-grained sandstones.

18-claystone, pale-reddish-purple(5RP 6/2)

17-mudstone, yellowish-gray(5 Y 7/2) interlayered with pale-reddish-purple(5RP 6/2)

16-sandstone and shale; sandstone is light-gray (N7), fine-grained, friable, with silica cement; interbedded with dark-gray(N3) shale

15-sandstone, pale-yellowish-brown(10YR 6/2), fine-grained, poorly sorted, well-indurated, calcareous, mottled with black patches of iron oxide cement, tabular cross-stratification

14-sandstone, grayish-orange(10YR 7/4) speckled with white, fine-grained, moderately sorted, friable, silica cement

13-mudstone and claystone, pale-reddish-purple (5RP 6/2) or light gray(N7); minor interbedded shale and pale-yellowish-orange (10YR 8/6), fine-grained sandstone

12-sandstone, moderate-orange-pink(5YR 8/4), medium-grained, poorly sorted, friable, silica and hematite cement, large-scale trough cross-stratification

11-sandstone and claystone; sandstone is light-red and grayish-yellow(5Y 8/4), fine-grained, poorly sorted, friable, silica and hematite cement, large-scale trough cross-stratification

10-sandstone, brick-red speckled with light-gray(N7), medium-grained, poorly sorted, friable, silica and hematite cement, large-scale trough cross-stratification

9-sandstone and mudstone, yellowish-gray (5YR 8/1), fine-grained, moderately sorted, friable, silica cement; interbedded mudstones are light gray(N7) to moderate gray(N7)

* degree of alteration inferred from reddish and purplish oxidation colors; yellowish-brown and grayish-orange colors interpreted as due to recent oxidation on the outcrop.

Figure 6. Measured section of the post-Mesaverde, pre-Baca oxidation zone. Section location: NE1/4 SE1/4 SW1/4 sec. 15, T.3N., R.16W.

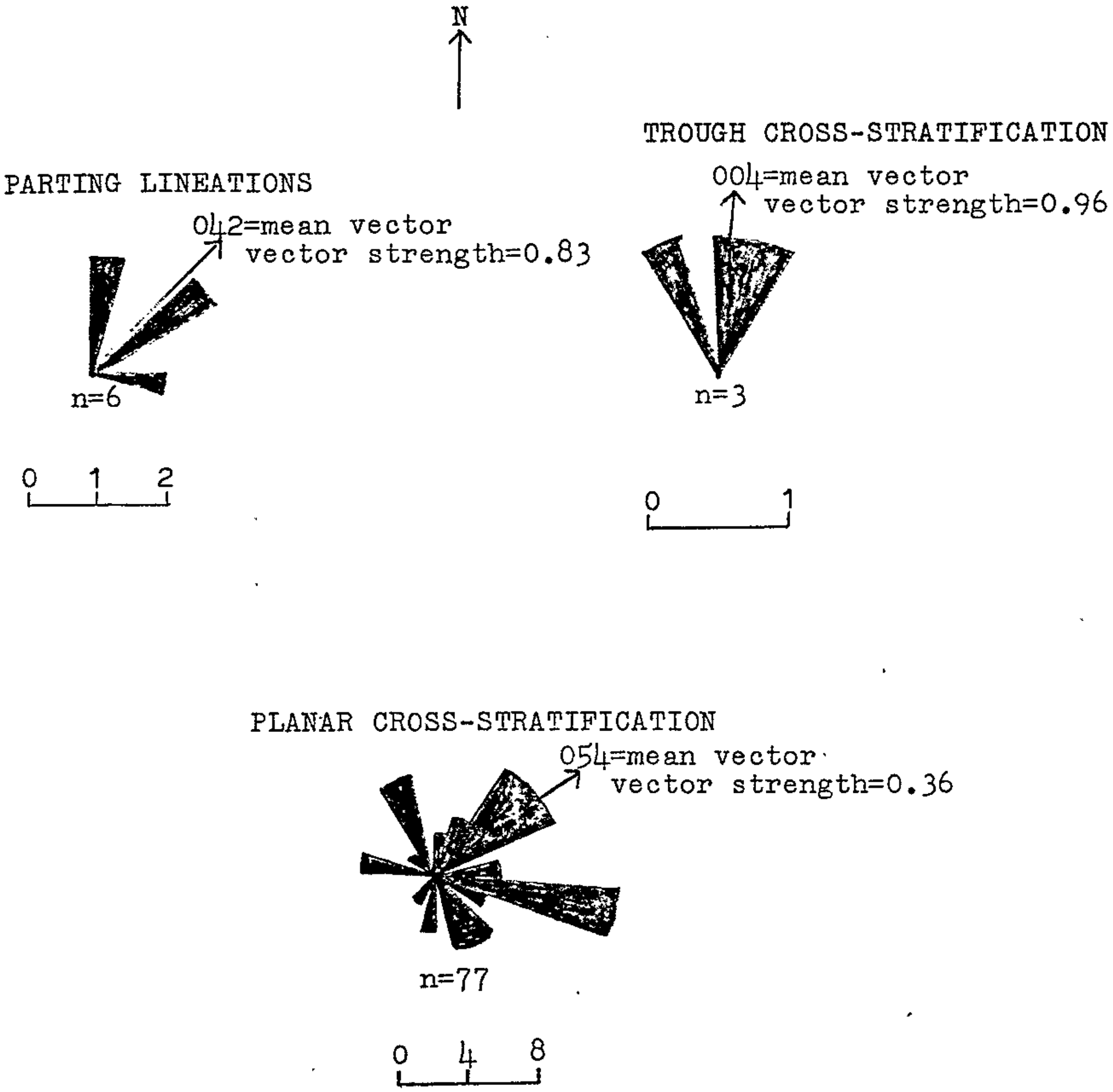


Figure 7. Rose diagrams of parting lineation, trough cross-stratification, and planar cross-stratification indicated current directions from Mesaverde Group sandstones in the TM-HD area. Vector directions were assigned to the parting lineations on the basis of associated cross-stratification. (See appendix C for a discussion of the current indicators used and methods of data analysis.)

A sample of black carbonaceous mudstone (TM 210), locally preserved within the oxidized zone, was collected for pollen analysis to determine both the primary age and environment of deposition of the Mesaverde rocks in the TM-HD area. The sample was collected at least 50 feet, stratigraphically, above the base of the oxidized zone (NW1/4 SE1/4 NE1/4, sec.22, T.3N., R.16W.). The following analysis and interpretations were made by Professor Karl R. Newman of the Colorado School of Mines (written commun., 1982).

Sample TM 210: black mudstone containing carbonized plant debris.
Palynomorph assemblage:
Spores: Deltoidospora spp., Cicatricosisporites spp., Cingulatisporites spp., Gleicheniidites spp., cf. Hamulatisporis, trilete-spinate spores, and Laevigatosporites spp.
Pollen: Tricolpites spp., Tricolpopollenites spp., Tricolporopollenites spp., Araucariacites sp., Classopollis sp., and Complexipollis sp.
Microplankton: none seen.

The age of this sample is Upper Cretaceous, most likely in the range of late Coniacian to early Santonian. This is indicated by the pollen genus Complexipollis which has such a range based on data from Utah and New Mexico (Tschudy, 1980). Tschudy reports Complexiopollis from the Crevasse Canyon Formation in New Mexico, and I have seen it from part of the Straight Cliffs Sandstone in Utah.

The residue from this sample contains abundant land-plant debris of various kinds, including resins. This fact, along with the apparent absence of marine microplankton, suggests a freshwater origin rather than brackish or marine. Proximity to a shoreline is impossible to determine. As most Upper Cretaceous assemblages do, this one suggests a warm temperate to subtropical climate, based on the general aspect of the spores.

Professor Newman´s observations support a fluvial/paludal environment of deposition for the Mesaverde Group in the TM-HD area. The lenticular fluvial sandstones are interbedded with mudstones representing interfluvial, paludal environments. The black carbonaceous mudstones are indicative of restricted, poorly-drained backswamp environments in which reducing conditions allowed for the preservation of the carbonaceous debris. Gray and pale-olive mudstones represent well-drained swamp conditions in which carbonaceous debris was largely destroyed through oxidation above the water table (shortly after deposition).

The Mesaverde Group of the TM-HD area may be correlative to either the Gallup Sandstone (Molenaar, 1973) or Crevasse Canyon Formation (Foster, 1964). The Crevasse Canyon Formation is composed of predominantly nonmarine deposits that overlie the Gallup Sandstone in the Zuni and San Juan Basins (Molenaar, 1977). Molenaar (1973) measured a section of Cretaceous rocks located approximately 14 miles northwest of the study area. He interpreted this section as being capped by nonmarine deposits, laterally and temporally equivalent to marine beds of Gallup Sandstone. He shows the non-marine Gallup Sandstone to be the Cretaceous unit of the western portion of the TM-HD area (see fig. 1 of Molenaar, 1973). Both the section location and the TM-HD area are shown by Molenaar (1973) to be in the southernmost portion of the Zuni Basin. Approximately 25 miles east of the TM-HD area, Chamberlin (1981) has correlated the Cretaceous unit underlying the Baca Formation with the Crevasse Canyon Formation, also based on studies by Molenaar.

The Huckleberry No. 1 Federal hole, located about two miles south of the TM-HD area, is reported to have intercepted 610 feet of non-marine, Upper Cretaceous rocks immediately below the Baca Formation, which Foster (1964) assigned to the Crevasse Canyon Formation. Support of this interpretation is given by both the presence of carbonaceous mudstones in the TM-HD area and coal units intersected by drill holes (completed by the New Mexico Bureau of Mines and Mineral Resources, 1982) in the western portion of the mapped area (Roybal, 1982, oral commun.), which may correlate to the Dilco Coal Member of the Crevasse Canyon Formation (see Gadway, 1959). Therefore the Mesaverde rocks of the TM-HD area are tentatively correlated with the Crevasse Canyon Formation.

During deposition of Mesaverde coastal plain deposits, the Cretaceous eperic sea was located to the northeast of what is now the Tejana Mesa area (Gadway, 1959). The north-northeasterly paleocurrent directions of Mesaverde streams/rivers determined in this study (fig. 7) are in general agreement with paleogeographic reconstructions based on shoreline trends (see fig. 53 of Hunt, 1956).

Post-Mesaverde, pre-Baca Oxidation Zone

A post-Mesaverde, pre-Baca weathering profile was first identified and described by Chamberlin (1981) in the Datil Mountains-Pietown area of west-central New Mexico. This paleosol is developed on the top portion of the Late Cretaceous Mesaverde Group (Crevasse Canyon Formation), immediately below a regional unconformaity at the base of the Eocene Baca Formation. The paleosol is characterized by oxidized reddish sandstones and purplish mudstones of the Crevasse Canyon Formation, which is normally a drab yellowish brown color. The weathering profile has a basal contact (a redox boundary) that typically follows sandstone-mudstone contacts and occasionally cuts bedding at a high angle in the form of "C"-shaped alteration fronts (similar in appearance to Wyoming-type uranium roll fronts). The thickness of the paleosol ranges from 25 to 150 feet and averages between 60 and 100 feet.

Chamberlin (1981) suggested that the soil may have formed between late Paleocene and middle Eocene time during a period of inter-Laramide quiescence, inferred from a well-dated weathering profile of similar characteristics that underlies Eocene age strata in the Denver Basin (Chapin and Cather, 1981; Soister and Tschudy, 1978). Numerous exposures of the paleosol between the Quemado area and the Bear Mountains area, north of Magdalena, indicate a minimum lateral extent of 70 miles (Chamberlin, 1982, oral commun.).

The paleosol has characteristics of pedalfer soils and has been interpreted (Chamberlin, 1981) to be the "C" horizon of a lateritic, tropical weathering profile, primarily on the basis of its great thickness. Evidence of iron enrichment is provided by the presence of hematite/limonite pebbles in the basal conglomerate of the Baca Formation, which were probably derived from erosion of a zone of iron enrichment at the top of the paleosol.

A zone of oxidized sandstones and mudstones (anomalously red and purple, respectively), in the TM-HD area, is stratigraphically situated within the uppermost Mesaverde Group (normally drab colored) and immediately below the Baca Formation. The average thickness of the oxidized zone is about 90 feet and it ranges from 0 to 160 feet. This zone is interpreted to be an interval of altered (oxidized) Mesaverde sandstones and mudstones produced by a pre-Baca weathering profile developed on the Mesaverde Group, in a similar manner as described by Chamberlin (1981) in the Datil Mountains area.

The two major characteristics of the pre-Baca oxidized zone are: 1) its purple and red colors and 2) the general absence of carbonaceous material in oxidized Mesaverde sandstones. The sandstones are typically very light red to brick red in color. The deeper shades of red occur in the lower half of the altered zone with the sandstones of the upper half being light shades of red or often the yellowish colors of unaltered Mesaverde sandstones. The most common anomalous color of the mudstones and claystones is pale reddish purple (5 RP 6/2). Black-carbonaceous mudstones and mudstone colors typical of the unaltered Mesaverde Group are not uncommon in the altered zone. One of these was sampled for a pollen and spore analysis (see pg. 22). Black carbonaceous plant material, which is common in the unaltered sandstones, is not found in the altered sandstones.

The vertical distribution of alteration colors can be seen in the measured section (fig. 6). The well-indurated, calcareous sandstones and siltstones that occur in both the altered and unaltered Mesaverde Group showed no signs of pre-Baca alteration. The grain size (fine to medium grained), bed forms, and thickness of the altered sandstones are identical to those of the unaltered Mesaverde Group sandstones. The red color of the altered sandstones is produced by hematite cement. Trace amounts of pyrite are found in the unaltered sandstones but are not seen in the altered sandstones.

The basal contact of the oxidation zone (a redox boundary) most often follows (parallels) sandstone/mudstone contacts but occasionally it cuts across sandstone beds at a high angle. The parallel nature of the contact is best exposed in sec. 16, T.3N., R.16W. At this location, the contact is between reddish sandstones of the altered zone and drab colored mudstones and argillaceous sandstones of unaltered Mesaverde Group.

At three localities, the basal contact of the color zone cuts bedding at a high angle. These contacts have been mapped as alteration fronts on Plate 1. Only chemical alteration fronts, apparently representing changes in ground water chemistry, were mapped. In the field, these alteration fronts ("C"-shaped) form reddish against yellowish color boundaries that cut across sandstone beds of otherwise uniform lithology and cementation. Permeability controlled alteration fronts, in which altered permeable sandstones are in lateral contact with unaltered, less permeable sandstones or mudstones, were not mapped as alteration fronts. A well developed alteration front is located at: NW1/4 NW1/4 SE1/4 sec. 22, T.3N., R.16W. This front cuts vertically across about 50 feet of sandstones and minor interbedded mudstones and claystones. As the redox boundary crosses the mudstones, it becomes indistinct and gradational, with tongues of unaltered mudstone projecting back from the alteration front, well into the zone of altered sandstone.

The upper contact of the pre-Baca oxidized zone coincides with the base of the Baca Formation. This contact is everywhere a low-relief, erosional unconformity. Conglomerates, common at the base of the Baca Formation, contain abundant Mesaverde Group-type clasts. These include gray, well-indurated, calcareous sandstones and siltstones and fine-grained, friable sandstones with colors characteristic of both altered and unaltered Mesaverde rocks. A few pale-reddish-purple (5 RP 6/2) claystone clasts were also seen in the conglomerates. No sandstone, siltstone, or claystone beds of similar appearance occur in the basal portion of the Baca Formation. Hematite-limonite clasts are locally present in the basal conglomerate.

The zone of oxidized Cretaceous rocks has been previously recognized and described in the Datil Mountains area as the "C" horizon of a tropical weathering profile of lateritic character (Chamberlin, 1981). It had also been interpreted as: (1) a Paleocene transition zone between the Baca Formation and the Mesaverde Group (Johnson, 1978); (2) a zone of reworked Mesaverde rocks making up the basal part of the Baca Formation (Bachman and others, 1957); (3) an intertonguing of the Baca with the Mesaverde Group (Willard and Givens, 1958); (4) a zone of post-Baca ground water alteration (Pierson and others, 1981).

It was reported, in the section describing unaltered Mesaverde Group rocks, that pollen from an unaltered carbonaceous mudstone collected within the oxidation zone (sample TM 210) yielded an age of late Coniacian to early Santonian (ca. 86-84 m.y. old). This age would place the sample within Late Cretaceous units of the Mesaverde Group (Molenaar, 1977). Numerous vertebrate fossils collected from the Baca Formation are of Eocene age (see Table 2 of Cather, 1980). Thus the color zone is not likely to be a zone of intertonguing Baca and Mesaverde beds, or a Paleocene transition zone between these two units. The lack of an obvious unconformity at the base of the oxidized zone and the fact that the lower color boundary occasionally cuts across bedding at a high angle, clearly indicates that the color zone is epigenetic, and not a zone of reworked Mesaverde material within the lower Baca Formation.

Except for the absence of carbonaceous debris in the altered sandstones, there are no other differences between the anomalously reddish and purplish colored rocks of the altered zone and the drab yellowish colored Mesaverde Group. The occurrence of oxidized and unoxidized Mesaverde-type clasts in the basal conglomerates of the Baca seems to require that the alteration was pre-Baca. The oxidized zone is therefore interpreted to have been produced by pre-Baca, sub-tropical weathering upon the Mesaverde Group in a similar fashion as described by Chamberlin (1981) for the amomalous color zone in the Datil Mountains-Pietown area. The major criteria used by Chamberlin (1981) in his interpretation of the altered zone as a lateritic weathering profile (paleosol) are, its great thickness (see Thomas, 1974), and the presence of banded hematite clasts (in the basal Baca Formation), which are similar in appearance to banded hematite found in laterites. The similar weathering profile thickness (60 to 100 feet) and occurrences of hematite-limonite pebbles in the basal Baca of the TM-HD area are supportive of a lateritic interpretation at TM-HD area also.

The zones of oxidized Cretaceous rocks in the TM-HD area and the Datil Mountains area occur at essentially the same stratigraphic position. Therefore, they are considered to represent one laterally continuous weathering profile formed prior to Baca deposition. The pre-Baca paleosol has also been noted at this stratigraphic position in the Gallinas Mountains and in Baca Canyon (Chamberlin, 1982, oral commun.) The latter is on the northeast flank of the Bear Mountains, about 70 miles east of the TM-HD area. The great lateral extent of the altered zone, indicative of widespread pedogenesis, would seem to preclude its possible interpretation as a zone of deep ground water alteration formed during deposition of the Baca Formation (Pierson and others, 1981).

Oxidation is the principal alteration effect, on the rocks of the Mesaverde Group, that characterizes the pre-Baca weathering profile. Much of the hematite cement, which is responsible for the red color of the sandstones, was probably derived from the oxidation of pyrite or other ferrous iron minerals indigenous to the Mesaverde Group. Vickers (1957) demonstrated the intrinsic oxidized and reduced nature of red and buff (yellowish) colored sandstones, respectively. In Vicker´s study of Cretaceous sandstones in the Black Hills of South Dakota, red oxidized sandstones, associated with hematite, were interpreted to be the result of weathering that extended down permeable beds, below an ancient erosion surface. The purple color of the altered mudstones of the TM-HD area is an oxidation effect produced through pigmentation by the ferric ion (Potter and others, 1980).

The outcrop colors of both the Mesaverde Group and the oxidation zone are partly a function of present day weathering. In subsurface, the bulk of the Mesaverde Group is gray in color (Foster, 1964) and is reduced in character (carbon rich, $FeS2$ common). Outcrop weathering produces the characteristic drab color (yellowish brown and gray) of the Mesaverde Group, which is indicative of hydrated $Fe2O3$ (goethite). The rocks of the oxidation zone, however, represent the base of a lateritic paleoweathering profile that is revealed by present day weathering as reddish and purplish oxidation colors indicative of nonhydrated $Fe2O3$ (hematite).

The charcteristics of the weathering profile of the TM-HD area are compared and contrasted to those of the profile in the Datil Mountains-Pietown area, in Table 3. Some of the differences between these profiles could be explained by local variations in the chemistries of the subsurface waters associated with the development of the profiles. A laterite is produced by acidic soil waters

Table 3. Comparison of oxidized Cretaceous rocks below the Baca Formation in the TM-HD area and in the Datil Mountains-Pietown area. (Characteristics of Datil Mountains-Pietown area oxidation zone from Chamberlin, 1981)

Similarities

1) Thickness of oxidized zones generally range from 50 to 100 ft; maxima of about 150 ft to 160 ft and minima of 0 to 25 ft.

2) Lower contact of oxidized zones (redox boundary) usually follows sandstone-mudstone contacts but locally cuts across permeable sandstone beds as "C"-shaped alteration fronts (geometry similar to Wyoming-type roll fronts).

3) Alteration (oxidation) developed on non-marine, carbon-rich upper Cretaceous sandstones and mudstones (Mesaverde Group) immediately below an unconformity overlain by the Eocene Baca Formation.

4) Zones of unoxidized (unaltered) sandstone and mudstone are common within the oxidized zones. Pollen/spore assemblages in carbonaceous mudstones within the altered zone are Late Cretaceous.

5) Clasts of banded hematite-limonite are found in the base of the Baca Formation.

Differences

1) Organic material, and, to a lesser degree, carbonate have been strongly leached from the upper portion of the altered zone in the Datil area. In the TM-HD area, there has been no apparent carbonate leaching and only minor destruction of organic debris.

2) Radiometric anomalies are common and locally continuous along the base of the oxidation zone and occur at most of the "C"-shaped alteration fronts in the Datil area. In the TM-HD area, none of the "C"-shaped alteration fronts were anomalous and the base of the oxidation zone contains only a few, weak radiometric anomalies. Chlorite zones associated with alteration fronts in Datil Mountains are notably absent in the TM-HD area.

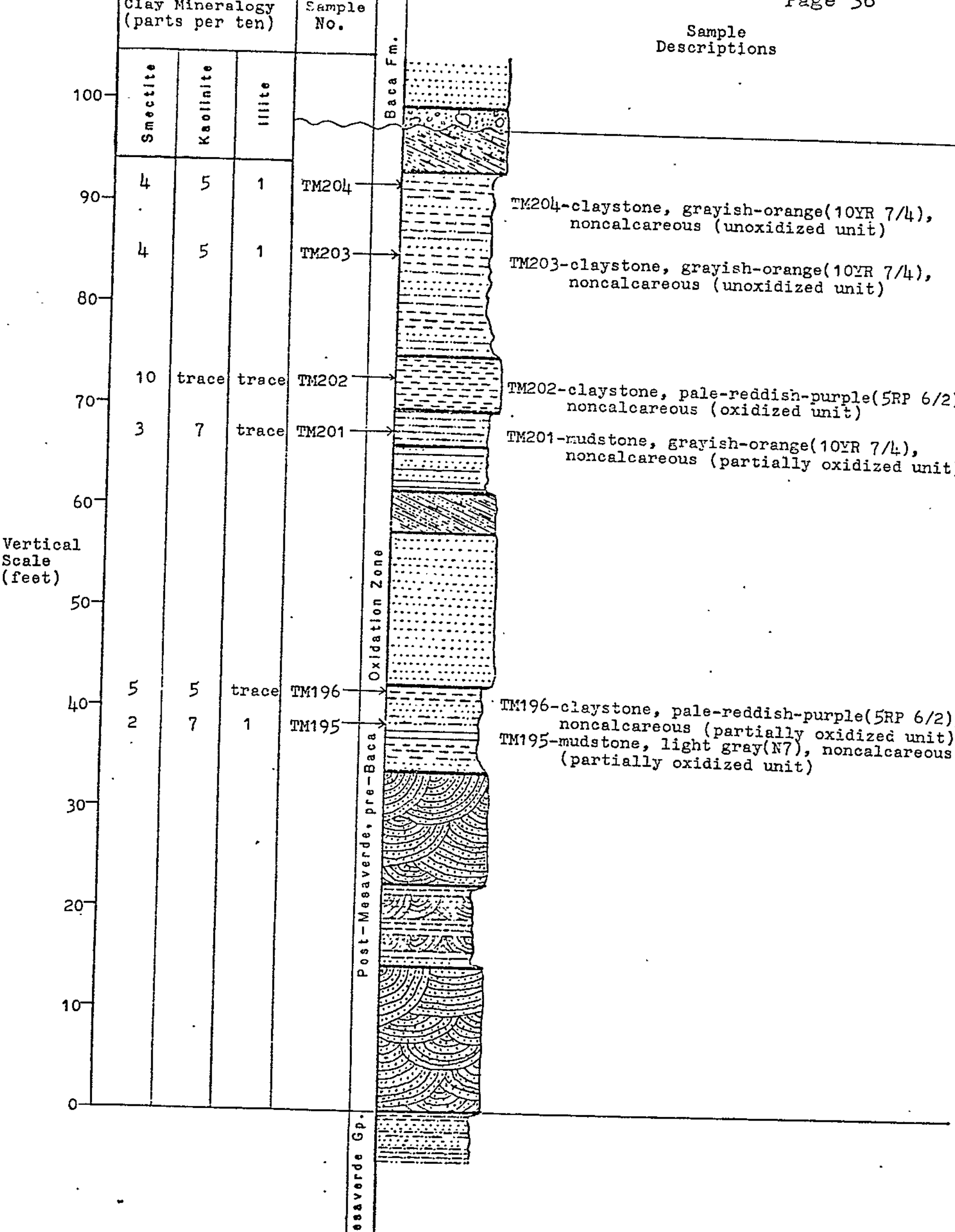
3) Diagenetic iron sulfides (forming concretions) are irregularly distributed throughout the Mesaverde sediments of the Datil area. In the Mesaverde rocks, these sulfides are typically altered to limonite (by recent weathering) and in the oxidation zone, the sulfides are typically altered to hematite (by pre-Baca weathering). Diagenetic sulfides are very rare in the Mesaverde sediments of the TM-HD area.

related to the surface accumulation and decomposition of organic matter. Acidic and oxidizing subsurface waters were apparently the cause of the extensive carbonate and organic leaching of rocks of the Datil Mountains profile. The subsurface waters associated with the weathering profile of the TM-HD area may have been less oxidizing and acidic as suggested by the presence of unaltered sandstones near the top of the profile and by the presence of more unaltered (carbon-rich and carbonate-rich) zones within the overall weathered zone. Alternatively, a greater volume of unaltered rocks within the altered zone, in the TM-HD section, could reflect a generally lower permeability (produced by well cemented sandstones) or differences in the paleotopography. Another alternative is that the oxidation of diagenetic iron sulfides, which are irregularly distributed throughout the Mesaverde sediments in the Datil-Pietown area, could have caused a significant decrease in the pH of soil waters, which in turn could account for lateral differences in the degree of alteration (eg. carbonate dissolution).

A preliminary evaluation of the lateritic weathering profile hypothesis was made through X-ray analysis (appendix B) of clay minerals in mudstones and claystones in both the altered and unaltered Mesaverde rocks. Laterite is an intensively weathered material rich in secondary oxides of iron, aluminum, or both (Alexander and Cady, 1962).

Laterites are typically formed on feldspar-rich and ferromagnesian-rich igneous rocks in well drained, subtropical to tropical environments. Kaolinite is the clay mineral produced in the central to lower portions of the lateritic profile, where silica remains in excess to alumina and/or iron (Singer, 1980). Kaolinitic zones grade downwards into smectitic zones near the base of lateritic profiles. Kaolinite is generally indicative of rock terrains that have undergone a high degree of leaching by acidic vadose and ground waters. Smectite is a clay indicative of poor drainage conditions and/or leaching by neutral to alkaline vadose and ground waters. Therefore, kaolinite in rock terrains generally represents a greater degree of weathering than that of smectite (Singer, 1981).

The clay mineral data from the measured section (fig. 8) show no systematic increase in the amount of kaolinite toward the top of the altered zone. Samples from the top of the altered zone in the Datil Mountains area (Table 4) also show no clear indication of kaolinite enrichment. However, kaolinite was found in slightly greater amounts in the altered zone (maximum of 7 ppt kaolinite, fig. 8) as compared to unaltered Mesaverde Group (maximum of 5 ppt kaolinite, fig. 8). Statistically significant sample populations (40-50 samples of each type) would be required to demonstrate a slightly higher degree of weathering for the altered zone versus the unaltered Mesaverde Group.



Smectite	Kaolinite	Illite	Sample No.
4	5	1	TM204
4	5	1	TM203
10	trace	trace	TM202
3	7	trace	TM201
5	5	trace	TM196
2	7	1	TM195

TM204-claystone, grayish-orange(10YR 7/4), noncalcareous (unoxidized unit)

TM203-claystone, grayish-orange(10YR 7/4), noncalcareous (unoxidized unit)

TM202-claystone, pale-reddish-purple(5RP 6/2 noncalcareous (oxidized unit)

TM201-mudstone, grayish-orange(10YR 7/4), noncalcareous (partially oxidized unit

TM196-claystone, pale-reddish-purple(5RP 6/2) noncalcareous (partially oxidized unit)

TM195-mudstone, light gray(N7), noncalcareous (partially oxidized unit)

Figure 8. Clay mineralogy of altered (oxidized) and unaltered (unoxidized) mudstones/claystones from measured section of oxidized Mesaverde Group in TM-HD area. See figure 6 for description of lithologic units.

Table 4. Clay mineralogy of claystones from the top of the pre-Baca oxidation zone in the Datil Mountains-Pietown area.* (See appendix B for analytical techniques and sample locations.)

Sample No.	Clay Mineralogy(parts per ten)			Color
	Smectite	Kaolinite	Illite	
RB 11	6	3	1	lt. purplish gray
RF 20	5	5	0	lt. purplish gray

*Samples collected by R. M. Chamberlin

The predominant clay mineralogy of the Baca Formation is smectite, which indicates a semi-arid (alkaline) depositional environment (see Baca Formtion section). The unaltered mudstones of the Mesaverde Group contain more kaolinite than the Baca mudstones since the sediments of the Mesaverde Group were eroded and deposited in wet, warm temperate to subtropical conditions. These wet conditions allowed extensive chemical weathering in both the source area and the depositional basin of the Mesaverde Group. Therefore, variations in the kaolinite content of the mudstones of the Mesaverde Group are probably a function of the primary mineralogy of the clay sediments and may also have been partly controlled by permeability and/or proximity to carbonaceous mudstones (ie. oxidation of carbonaceous mudstones produces acidic subsurface waters that alter smectite to kaolinite).

Variations in the mudstone clay mineralogy of the altered zone may reflect both the primary (detrital and diagenetic) mineralogy of the Mesaverde mudstones and/or secondary alteration produced by the lateritic weathering. Though the clay mineral data does not demonstrate the presence of a lateritic weathering profile, it also does not eliminate it. Alteration of preexisting clay minerals (such as smectite) to kaolinte in a lateritic profile would only be expected to occur in: 1) the upper portions of the profile where clays are exposed to subsurface waters high in organic acids derived from surface decay of vegetal matter, and 2) in permeable zones exposed to a greater degree of leaching. Clay data from the altered zones in both the TM-HD area and the Datil area may be interpreted to indicate that the altered zones at both locations were part of the "C" soil horizon and were therefore too low in the profile to have undergone clay mineral alteration by the tropical weathering.

The C-horizon is the basal horizon of a soil profile and consists of only slightly altered parent material (Birkeland and Larson, 1978). In the TM-HD area, this thick oxidation zone is interpreted as a product of chemical weathering (Ollier, 1969). Therefore, the oxidation zone may be classified as a soil-stratigraphic unit, which is defined in the AGI Glossary (1974) as:

> A soil whose physical features and stratigraphic relations permit its consistent recognition and mapping as a stratigraphic unit. It is formed essentially in place from underlying rock-stratigraphic units that may be of diverse composition and geologic age, and it may comprise one or more pedologic units or parts of units ... .

It is apparent that pre-Baca erosion has removed the "A", "B", and parts of the "C" soil horizons in the TM-HD area since oxidation and minor destruction of carbonaceous debris are the only alteration (weathering) effects observed. Original lateral variations in thickness of the weathered zone are considered to reflect varying depths of active (oxidizing) paleo-groundwater flow (Lelong and others, 1976; Chamberlin, 1981) which was a function of the paleolandscape and permeability variations within the Mesaverde Group. The local absence of the altered zone in the western part of the TM-HD area, is attributed to an originally thin zone of weathering, rather than to deep scouring by an early Baca paleochannel (see Chamberlin, 1981).

A laterite paleosol interpretation for the pre-Baca (pre-Eocene) weathering profile of west-central New Mexico is well supported in the literature. Paleosols of similar age and character are located near Sonora, Mexico (Abbott and others, 1976), along the southern United States from Arkansas to Georgia (Hunt, 1972), in the northern Great Plains (Pettijohn, 1966), and in the Denver Basin (Soister and Tschudy, 1978).

The formation of a lateritic weathering profile requires subtropical to tropical climatic conditions. As was discussed earlier, on the basis of pollen analysis, warm temperate to subtropical environments were known to have existed during deposition of the Mesaverde Group in the TM-HD area. The persistence of warm-wet conditions suitable for pedalfer-type weathering, at least through the Paleocene, are indicated by tropical flora found in the Vermejo and Raton Formations of northern Mew Mexico (Ash and Tidwell, 1976). Since the Mesaverde sediments were deposited on a wet coastal plain (implies high-water table), a pervasive lowering of the water table is an inherent implication of the pre-Baca weathering profile. Epeirogenic uplift and/or a progressively decreasing precipitation level could account for a widespread lowering of the water table, which would allow for the seasonal water table fluctuations necessary to produce a lateritic weathering profile. Uplift, however, is not required here, since by early Baca time, the climate was apparently sub-arid, as indicated by calcic paleosols in basal overbank deposits of the Baca Formation (Cather, 1980).

Cenozoic Rocks

Baca Formation

The Baca Formation was defined by Wilpolt and others (1946) as the lower non-volcanic portion of the Datil Formation of Winchester (1920). The designated type area for the Baca Formation is in Baca Canyon in the Bear Mountains north of Magdalena, New Mexico, but Baca lithologies described by Wilpolt and others (1946) are based on exposures in the Joyita Hills-Carthage area (Willard, 1959). For descriptions of the Baca Formation, see: Tonking (1957), Willard (1959), Potter (1970), Snyder (1971), Johnson (1978), Massingill (1979), Cather (1980), and Chamberlin (1981). Johnson's (1978) work is a comprehensive analysis of the provenance and genesis of the Baca Formation.

The Baca Formation is generally described as a red bed sequence of sandstones, conglomerates, claystones, and mudstones (Johnson, 1978). Equivalents to the Baca Formation include the Eagar Formation of eastern Arizona (Sirrine, 1956; Johnson, 1978) and some probable early Tertiary gravels of east-central Arizona (Hunt, 1956; Pierce and others, 1979; Johnson, 1978). The Baca Formation and its equivalents form a discontinuous outcrop belt from Socorro, New Mexico to the Mogollon rim in Arizona (Johnson, 1978).

Cather (1980) summarizes fossil age dates for the Baca Formation, most of which are middle to late Eocene. A latite tuff-breccia of the Spears Formation (basal unit of the Datil volcanic field), from the northern end of the Joyita Hills in Socorro County, has been dated by the K-Ar method as 37.1-m.y.-old (Weber, 1971). Since this date falls just above the Eocene-Oligocene boundary, and the Baca-Spears contact is typically conformable, the bulk of the Baca Formation is probably of middle Eocene to late Eocene age.

The Baca Formation rests unconformably upon the Mesaverde Group throughout western New Mexico and overlies older Cretaceous strata (Mancos Shale) in the vicinity of the Arizona-New Mexico state line (Snyder, 1971). Chamberlin (1981) has shown that the so-called "transition zone", between the Mesaverde Group and the Baca Formation in the Datil Mountains area (see Snyder, 1971; Johnson, 1978) is more likely part of a pedalfer-type weathering profile developed on the Mesaverde rocks prior to deposition of the Baca Formation. The contact of the Baca Formation with the underlying Cretaceous rocks is a widespread erosional unconformity of low relief or locally an angular unconformity (Chamberlin, 1981). The upper contact of the Baca Formation is usually a conformable (gradational) contact with the Spears Formation of early Oligocene age (Chamberlin, 1981). In the TM-HD area, the Baca Formation is also unconformably overlain (slight angular unconformity) by the Fence Lake Formation of Miocene age.

Most previous studies have interpreted the depositional environment of the Baca Formation to be dominantly fluvial. Cather (1980) has also recogized a lacustrine environment in the Gallinas Mountains area. Paleoclimatic interpretations made for the Baca Formation include: arid to semi-arid (Snyder, 1971; Cather, 1980; Chamberlin, 1981), semi-arid to subhumid (Johnson, 1978), and subhumid (Massingill, 1979). Johnson (1978) has recognized a dominantly eastward paleocurrent direction for Baca sandstones and interpreted the Mogollon Highland of southern Arizona to be the principal source area for the western and central portions of the Baca Formation and its equivalents. The Sierra-Sandia-Morenci uplift also contributed sediments to the southern part of the Baca Basin (Chapin and Cather, 1981).

The Baca Formation apparently thickens toward the south of its exposures in the Datil-Pietown area of New Mexico (Snyder, 1971). The oldest Baca beds should lie south of the outcrop belt along the original east-west axis of the Baca Basin (Chamberlin, 1981). Younger beds visibly overlap wedge outs of older beds (onto paleotopographic highs) at the base of the Baca Formation in the Datil Mountains area.

The Baca Formation in the TM-HD area consists of interbedded sandstones, mudstones, and conglomerates. The lower contact is a low-relief, erosional unconformity cut on the Mesaverde Group. At Mariano Mesa, where the Baca Formation is conformably overlain by the Spears Formation, its original thickness is about 600 feet. Elsewhere in the TM-HD area, the Baca Formation is unconformably overlain by the Fence Lake Formation. Regional stratigraphic relationships at the base of the Fence Lake Formation indicate gentle southeastward tilting prior to its deposition. In addition, the Baca Formation thins to the northwest, beneath the Fence Lake Formation. In an exposure under Tejana Mesa (section 36, T.3N., R.17W.), the Baca Formation is only 25 feet thick. The Baca Formation wedges out in a northwesterly direction under Tejana Mesa. The northernmost exposure of Baca beds in the mapped area, northeast of Hubbell Draw, is 250 feet thick. In the area between Mesa Tinaja and Tejana Mesa, the Baca Formation is unconformably overlain by the Bidahochi(?) Formation, which is inset into the Fence Lake and older formations.

Baca sandstones are fine to coarse grained, usually friable, and most often poorly cemented with calcite and/or silica. Most Baca sandstones are very pale orange (10YR 8/2) to pale yellowish orange (10YR 8/6). Sandstones at the base of the Baca Formation are normally coarse grained and moderate pink (5 R 7/4). A thin-section of one of the orange colored sandstones (TM 187) was studied and found to be a fine-grained, poorly sorted arkose (McBride classification, 1963) with subequal amounts of calcite and silica cement. The calcite cement appeared to predate the silica cement.

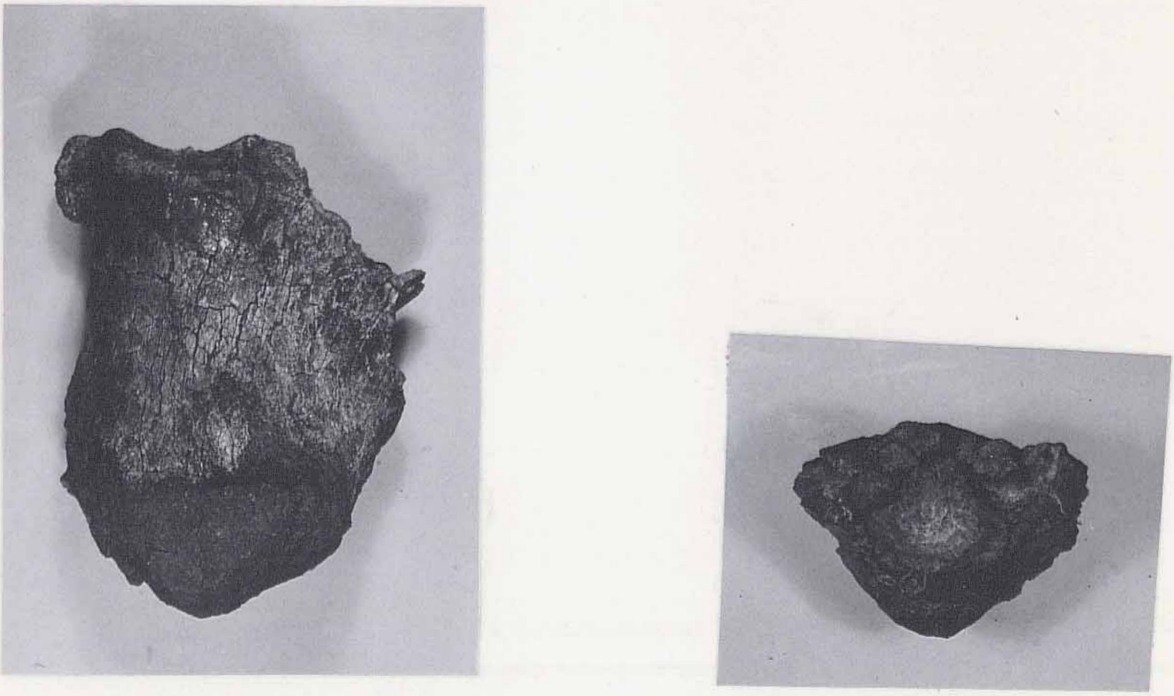
The Baca sandstones are commonly massive-looking, although they often exhibit medium-scale, trough cross-stratification. The sandstones are lenticular, with thicknesses averaging from 10 to 15 feet and maximum thicknesses up to about 50 feet.

Conglomeratic sandstones and conglomerate lenses are found throughout the Baca Formation. Clast lithologies are dominated by quartzite with lesser amounts of milky quartz, jasper, silicified wood, friable sandstone (Baca sandstone), and minor metaconglomerate and metavolcanics. Excluding silicified wood, the clasts are typically well rounded and dominantly pebble sized. The common occurrence of well-rounded lag gravels on weathered Baca outcrops reflects the poorly-cemented nature of the conglomeratic sandstones. Both matrix-supported and clast-supported (less common) units were observed in the Baca conglomerates. The conglomerates are either crudely bedded or nonbedded.

The basal Baca Formation (0-10 ft) is commonly, but not always, conglomeratic. This basal conglomerate differs from the rest of the Baca conglomerates in that the clasts consist mostly of well-indurated, gray, calcareous sandstones and siltstones, light-red and pale-yellowish-orange (10YR 8/6), fine-grained sandstones, and subrounded, hematite-limonite pebbles. The sandstone clasts range in size from granules to boulders. An example of this lithology may be found at the top of the measured section (see unit 21 in fig. 6). The gray sandstone and siltstone clasts appear to be identical in grain size, texture, and composition to beds found in the underlying Mesaverde Group. Throughout most of the mapped area, the basal conglomerate consists mainly of widely scattered, matrix-supported sandstone pebbles with a minor amount of well-rounded quartzite pebbles.

Baca mudstones are typically dark reddish maroon in color. They usually range in thickness from one to ten feet. Some well exposed mudstones near the base of the Baca Formation (sec. 27, T.3N., R.16W.) contain white carbonate nodules and root-mottling near their tops. The clay mineralogy of one mudstone sample (SW1/4 SE1/4 SW1/4, sec. 21, T.4N., R.15W.), was determined by X-ray diffraction to be nine ppt (parts per ten) smectite, one ppt kaolinite, and trace illite (see Appendix B for clay analysis procedures). Johnson (1978) reported 11 mudstone and claystone samples from the Baca Formation of Catron County, which included one from the TM-HD area, to be dominantly smectite with subordinant illite and kaolinite.

Fossil fragments of a titanothere, collected by the author on the flank of the unnamed mesa in the northernmost portion of the TM-HD area (SE1/4 SE1/4 SW1/4, sec. 21, T.4N., R.16W.), are apparently similar to those found nearby in the Baca Formation by Schiebout and Schrodt (1981). The fragments found in this study were identified and dated by Dr. Donald L. Wolberg of the New Mexico Bureau of Mines and Mineral Resources (written communication, 1982) and consist of a large foot fragment (159mm long, 135mm wide) and an atlas vertebra (see figs. 9 a,b). These fossils were found together in a sandstone of the upper Baca Formation. The large size of the foot fragment is indicative of a relatively advanced titanothere, which in turn indicates a late Eocene to early Oligocene age. Titanothere skulls and limb bones were among the fossils found by Schiebout and Schrodt (1981) within the TM-HD area on the west side of Mariano Mesa. They have identified these fossils as being Chadronian (latest Eocene-early Oligocene) in age.



(a) (b)

Figure 9. (a) Foot fragment of a titanothere; measures 159 mm long and 135 mm wide, (b) atlas vertebra of a titanothere found immediately adjacent to the foot fragment. Collected from the Baca Formation (SE1/4 SE1/4 SW1/4 sec. 21 T.4N., R.16W.). Identified by Dr. D. L. Wolberg (written commun., 1982)

Paleocurrent measurements were made on parting lineations within Baca sandstones. The data, which are presented on a rose diagram (fig. 10), indicate a dominant easterly transport direction. Trough axes were usually too poorly exposed to be measured.

The Baca Formation of the TM-HD area is interpreted to consist of fluvial sandstones and conglomerates interbedded with mudstones, which represent suspended load deposits on interfluvial floodplains. Root mottling and calcite nodules in the mudstones represent weak development of calcic soil horizions. The pedogenic features, along with the dominant smectite clay mineralogy, are indicative of a semi-arid (desert) environment (Dregne, 1976) during deposition of the Baca Formation. Cather (1980) also reports the presence of rare, pedogenic "caliches" in the Baca Formation as evidence of semi-arid conditions. The average east-southeastward paleocurrent direction of the TM-HD area (fig. 10) is in agreement with an overall easterly current direction for the Baca sandstones reported by Snyder (1971) and Johnson (1978). When the 580 foot thickness of the Baca Formation in the mapped area is compared to the subsurface thicknesses of up to 2500 feet (Snyder, 1971) to the southeast, it is apparent that the TM-HD area lies along the northern flank of the generally east-west trending Baca basin. Lower beds of the Baca Formation probably wedged out in a northerly direction toward the margin of the basin. Exposed

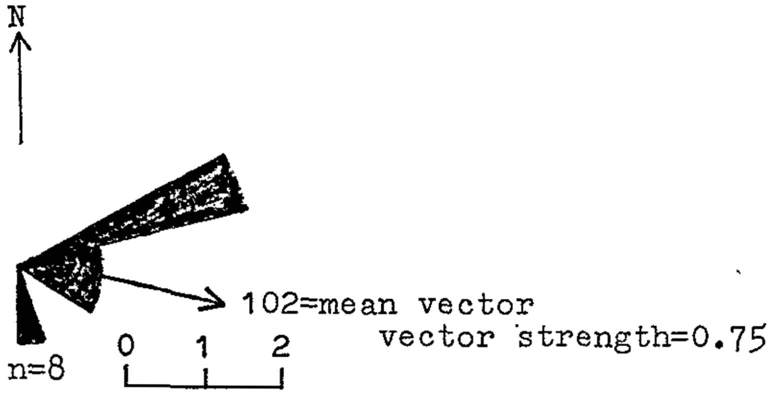


Figure 10. Rose diagram of parting-lineation, paleocurrent data from the Baca Formation in the vicinity of Mariano Mesa. Vector directions are assigned to the lineations on the basis of associated cross-stratification.

thicknesses of Baca Formation in the Datil Mountains (1800 feet; Chamberlin, 1981) could be explained by greater sedimentation rates along a broad northeast-trending Laramide syncline (Acoma Sag). The southern end of the Acoma Sag has apparently been reactivated by late Cenozoic extension (Red Lake and Hickman fault zones) to form a synclinal horst (Chamberlin, 1981; Wengerd, 1959).

Spears Formation

The name "Spears" was originally applied to the basal member of the Datil Formation (Tonking, 1957). Weber (1971) later raised the Datil Formation to group status and Chapin (1971) raised the Spears Member to formation status. At its type locality in the Bear Mountains, Socorro County, New Mexico, the Spears Member (now formation) was first described as a 1350 foot thick unit of latitic tuffs and volcaniclastics that overlie the Baca Formtion and underlie the Hells Mesa Member of the Datil Formation (Tonking, 1957). The Spears Formation represents a basal volcaniclastic apron of intermediate composition shed from the heart of the Datil-Mogollon volcanic field (Chapin and others, 1978). The formation is of early Oligocene age, approximately 37 to 33 m.y. old (op. cit.).

Willard (1959) referred to equivalents of the Spears Formation as the latite facies (Tdl) of the Datil Formation, which he recognized as grading laterally into water-deposited sediments (volcanic sedimentary facies, Tds) west of Pietown. Westward from the Datil Mountains, the bulk of the Spears Formation consists of intermediate composition pyroclastic breccias (laharic flows) of the Dog Springs Member, which grade laterally (westward) into the volcaniclastic wackes found in the TM-HD area (Chamberlin, 1982, oral commun.).

An erosional remnant of the Spears Formation is exposed on the flanks of Mariano Mesa in the east part of the mapped area. The basal Spears contact here is gradational with the Baca Formation and the upper contact is an unconformity buried by the Fence Lake Formation.

The Spears Formation consists mostly of interbedded, light-gray (N7) volcanic wackes and pale-red (10 R 6/2) claystones. These units commonly appear as very uniform, thin to medium-bedded (Ingram, 1954), laterally continuous beds. Minor cross-stratification was seen in the uppermost portion of the Spears Formation on the east side of Mariano Mesa. Soft sediment deformation was observed at a few localities near the base of the Spears Formation (fig. 11).

The volcanic wackes and claystones contain abundant clasts of white, rhyodacite/latite porphyry characterized by phenocrysts of hornblende, biotite, and plagioclase. These clasts range in size from granule to cobble and are randomly scattered throughout the formation. In thin-section, one Spears sandstone sample (TM-176) was found to be a lithic,

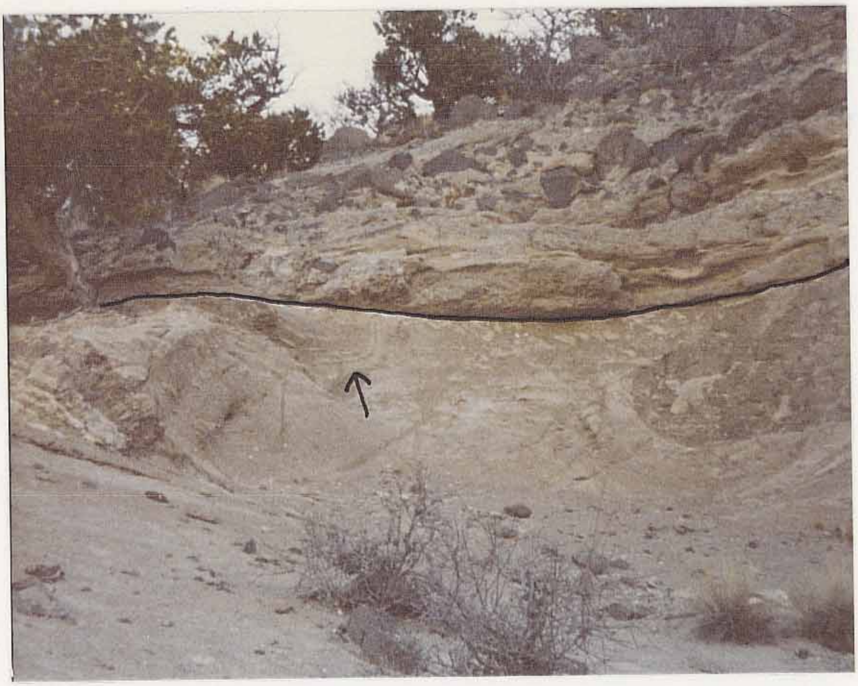


Figure 11. Basal contact of the Fence Lake Formation unconformably overlying the Spears Formation at Mariano Mesa (NE1/4 NE1/4 SW1/4 sec. 21, T.3N., R.15W.). Contorted bedding (arrow) in the Dog Springs Member of the Spears Formation is a widespread phenomena attributed to wet-sedimentary deformation (Chamberlin, 1981).

volcanic wacke. It is rich in very poorly sorted, sand-sized grains of plagioclase, hornblende, and fragments of porphyritic lava. The sample consists of about 40 percent matrix and 20 percent calcite cement.

The gradational nature of the Baca-Spears contact is well exposed in the arroyo east of Cottonwood spring (N1/2 N1/2 sec. 22, T.3N., R.15W.). At this locality, the white, rhyodacite/latite porphyry clasts common in the Spears Formation are found within the dark-reddish-maroon mudstones of the upper Baca Formation. This unit of mixed lithology (Baca and Spears) is about 10 feet thick.

Fence Lake Formation

The informal name "Fence Lake gravels" was initially applied to deposits of volcanic-rich gravels in the vicinity of Fence Lake, New Mexico (Marr, 1956; Foster and others, 1959). McClellan and others (in prep.) have named and proposed a type section (NE1/4 sec. 1, T.4N., R.18W.) for the Fence Lake Formation, located on Santa Rita Mesa about three miles southeast of the town of Fence Lake. At the type section, approximately 220 feet of conglomerates, rich in volcanic clasts, and sandstones rest unconformably on Late Cretaceous rocks.

Previous maps combined the Spears and Fence Lake Formations, where overlying the Baca Formation, as the "volcanic sedimentary facies" (Tds) of the "Datil Formation"

(Dane and Bachman, 1956; Willard, 1957; Willard and Weber, 1958), but where the Fence Lake Formation rests upon the Mesaverde Group, it was mapped as undifferentiated Tertiary sediments (Dane and Bachman, 1956). Chamberlin (1981) recognized Late Tertiary conglomerates (equivalent to the Fence Lake Formation) as unconformably overlying the Spears Formation in the Pietown area. At Tejana Mesa, the Fence Lake Formation is conformably overlain by the "Basalt of Tejana Mesa".

Campbell (1982) has mapped the Fence Lake Formation in the Cerro Prieto and Dyke quadrangles, located just north of the Tejana Mesa quadrangle, as unconformably overlying a late Oligocene basaltic dike trend. This trend has been dated at 27.67 +/- 0.59 m.y. (Laughlin and others, 1979). Laughlin and others (1979) have dated several basalt flows in the Springerville (AZ) and North Plains area, most of which range in age from 1 to 3 m.y. old. Older flows that stand in high topographic positions, such as Tejana Mesa, typically yield Pliocene ages (approximately 3-5 m.y. old). Assuming the basalt flows on Tejana Mesa to be Pliocene, then the Fence Lake Formation is believed to be mostly Miocene in age.

The Fence Lake Formation in the TM-HD area consists of a basal conglomerate (often bouldery), which is dominated by basaltic and rhyodacite clasts, overlain by fine to medium-grained sandstones. The formation is well exposed on the flanks of Tejana Mesa, Mesa Tinaja, Mariano Mesa, and an unnamed mesa in the northernmost portion of the map area.

The basal contact of the Fence Lake Formation is regional angular unconformity of moderate relief. At Mariano Mesa, there is as much as 500 feet of relief on the west side of a paleohill (held up by the Spears Formation) that was buried by the Fence Lake Formation. The Fence Lake-Spears contact (fig. 11) here slopes five degrees to the west-southwest. Elsewhere in the TM-HD area, the Fence Lake Formation rests upon a relatively flat erosion surface developed on the Baca Formation (fig. 12). In the Datil Mountains-Pietown area, the Fence Lake equivalents have been faulted and gently tilted. The horizontal attitude of the Fence Lake Formation in the TM-HD area would require some post-Fence Lake tilting to the southeast, if a northwestward primary dip is assumed.

The upper contact of the Fence Lake Formation is formed by basalt flows at Tejana Mesa and Mesa Tinaja. The stratigraphic thickness of the Fence Lake beds under these mesas averages about 180 feet. A 10-to-25-foot-thick transition zone exists between the Fence Lake sandstones and the mesa-capping basalts. This zone consists of sandstones and conglomerates dominated by scoria granules and pebbles that grade upward into generally non-cemented, dark-brown, bedded cinder deposits (air-fall deposits), which are directly beneath the basalt flows. This zone was too thin two to four percent of sanidine-biotite bearing rhyolite grains (tuffs?) are also present along with traces of quartz.

Above the conglomerates the Fence Lake Formation is composed mainly of very-light-gray (N8) to pinkish-gray (5 YR 8/1), fine to medium-grained sandstones with rare basaltic pebble lenses. Lithic fragments are less abundant in these sandstones as compared to the matrix sandstones of the conglomerates.

Based on similar lithology and topographic expression, the volcanic-rich conglomerates and sandstones of the TM-HD area are correlated to the Fence Lake Formation of McClellan and others (in prep.) located approximately 10 miles north of the TM-HD area (fig. 13). In addition, the Fence Lake Formation may be, in part, time equivalent to the lower member of the Bidahochi Formation of Arizona and northwest New Mexico (fig. 13). The Bidahochi Formation consists of a lower lacustrine member, a medial volcanic member, and an upper fluvial member (Repenning and others, 1958). The Fence Lake Formation may represent an alluvial-facies component of the lower lacustrine member or may be older than the classic lower Bidahochi rocks (J. W. Hawley, oral commun., 1982). A portion of what is probably the upper fluvial member of the Bidahochi Formation is inset into the Fence Lake Formation in the TM-HD area. Both the Bidahochi(?) and the Fence Lake Formations of the TM-HD area

Figure 12. Basal contact of the Fence Lake Formation unconformably overlying the Baca Formation along the flank of the unnamed mesa in the northernmost portion of the TM-HD area (SE1/4 SE1/4 SW1/4 sec. 21, T.4N., R.15W.).

and too laterally restricted to be mapped as a separate unit. On the geologic map, these basaltic pyroclastic beds are grouped with the Fence Lake Formation.

The basal conglomerate zone of the Fence Lake Formation is usually less than 50 feet thick. This conglomerate is locally absent under Tejana Mesa and is only locally present in the vicinity of Mesa Tinaja. The conglomerate is the only portion of the Fence Lake Formation preserved on both Mariano Mesa and the unnamed mesa in the northernmost portion of the mapped area. The conglomerates are generally nonbedded and contain rounded clasts ranging in size from granules to boulders that have diameters of up to three feet. The clasts are dominantly basalt or basaltic andesite(?) with varying amounts of rhyodacite and rhyolite, and minor amounts of chert, sandstone, and quartzite. The rhyolites are porphyritic and contain phenocrysts of quartz, biotite, and sanidine. At Tejana Mesa, the rhyolitic fragments normally make up 5 to 20 percent of the clasts while at Mariano Mesa they are found in only trace amounts. In thin-secton, a sandstone from the conglomerate zone of Tejana Mesa (TM-216) was found to be a coarse-grained, poorly sorted, volcanic-rich, lithic arenite (McBride classification, 1963), which is cemented with calcite. About 1/3 of the lithic fragments in the thin-section are basaltic and the rest are mostly intermediate lavas with abundant phenocrysts of plagioclase and hornblende. About

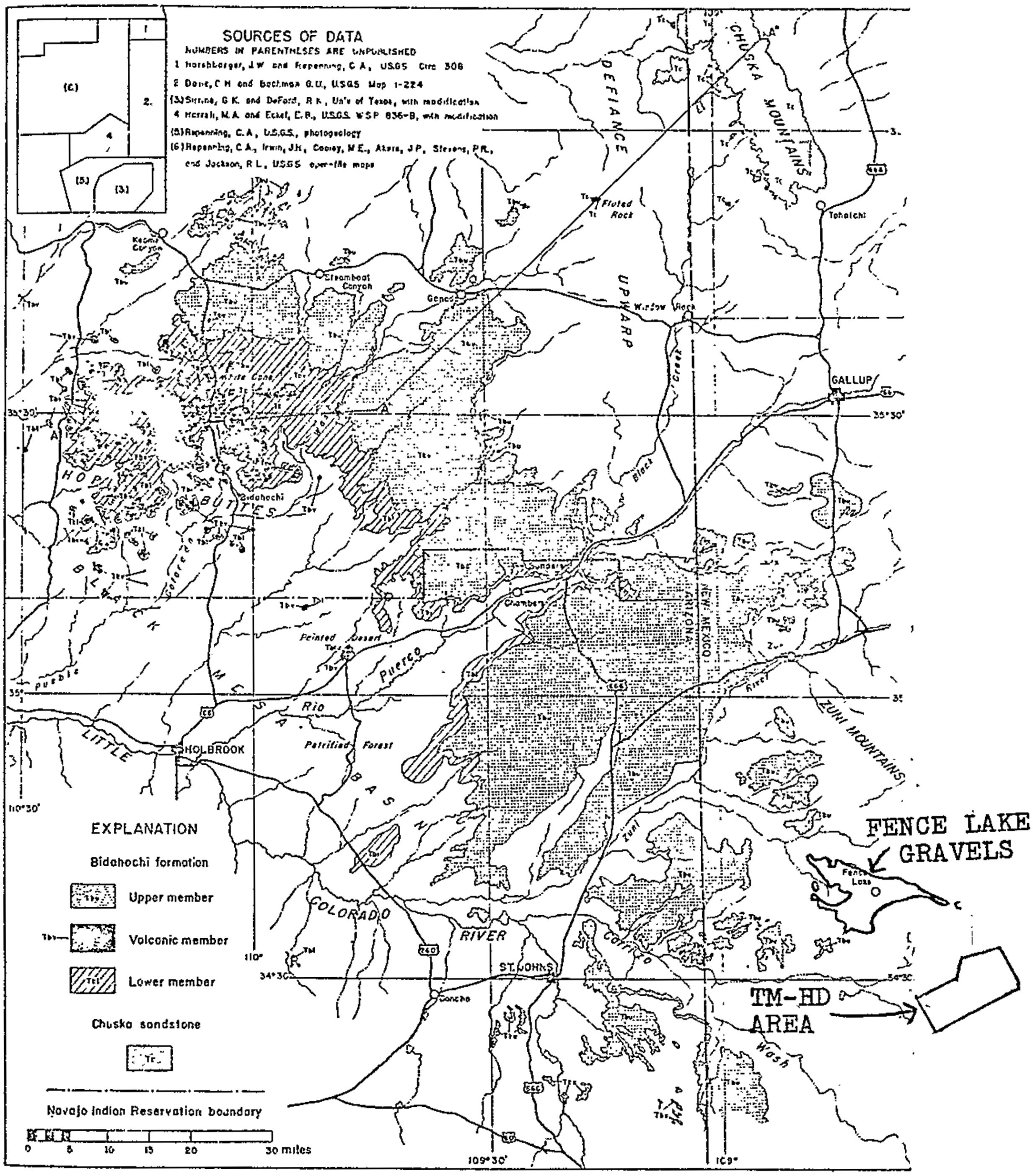


Figure 13. Map showing the location of the TM-HD area relative to the Fence Lake Gravels (Tu of Dane and Bachman, 1965) and the three members of the Bidahochi Formation. (Adapted from Repenning and others (1958) and Dane and Bachman, 1956)

were probably deposited by a northwest flowing drainage system, off the Datil-Mogollon volcanic field. The rhyolitic clasts of the Fence Lake beds were probably derived from ash-flow tuffs of the Datil volcanics and the basaltic boulders may have been locally derived from late Oligocene basalt flows (now completely removed by erosion) associated with the dike system previously mentioned (see pg. 55). Early Miocene basaltic andesites capping the Mangas Mountains, located about 25 miles south-southeast of the TM-HD area, are another possible source of the smaller basaltic clasts (Chamberlin, oral commun., 1982).

"Basalt of Tejana Mesa"

The "Basalt of Tejana Mesa" is the informal nomenclature proposed and used in this study for the basalt that caps Tejana Mesa, Catron County, New Mexico. The basalt capping the volcanic vent at Mesa Tinaja (Plate 1) is interpreted to be equivalent to the basalt on Tejana Mesa, since both are found at about the same elevation (when comparing portions of the basalt caps not affected by later faulting). In addition, Mesa Tinaja is found along the same northeasterly trending structural zone from which the Basalt of Tejana Mesa was erupted. The "Basalt of Tejana Mesa" is inferred to be Pliocene on the basis of its high topographic position, which is similar to other basalt flows in the Springerville (AZ) and Mount Taylor areas that typically yield Pliocene ages approximately 3-5 m.y. old (Laughlin and others, 1979; Luedke and Smith, 1979).

The preserved thickness of basaltic lava, along the portion of Tejana Mesa within the TM-HD area, ranges from 5 to 50 feet and averages 15 to 25 feet. On Mesa Tinaja, about 200 feet of basalt lava is preserved. The flow rocks consist of porphyritic olivine-augite basalt containing phenocrysts of olivine and pyroxene with an augite/magnetite, microlitic matrix. The olivine often shows alteration to yellow-brown iddingsite. Xenoliths of dunite/peridotite were observed in the basalt. The flows rest on a 10-to-25-foot-thick, poorly exposed transition zone consisting of scoria-clast dominated conglomerates and sandstones that grade upward into generally non-cemented, crudely bedded cinder deposits that directly underlie the basalt.

Mesa Tinaja lies within a northeast-southwest trending structural zone (Tejana Mesa fault zone, fig. 16). This zone is defined by normal faults and basaltic dikes oriented in this direction, and by a greater thickness of basaltic rocks within the zone. A major fault (approximately 250 feet of stratigraphic throw) in the structural zone dies out at Mesa Tinaja as a monoclinal flexure that has downwarped the basal contact of the basalt cap, on the southwest side of the mesa. A volcanic vent and feeder dike, trending northeastward, are exposed on the north flank of Mesa Tinaja. A small volcanic (plug) is also exposed along this dike trend, northeast of the mesa. The through-going structural zone contains approximately 250 feet of basaltic rocks where it crosses the southwestern flank of Tejana Mesa near El Porticito (outside the mapped area). This zone is expressed as a graben-like structure, on the east side of Tejana Mesa, where it contains abundant scoria. Large areas of the scoria are red in color (outlined on geologic map, Plate 1) and occupy the central portion of the structural zone, while black scoria is located at the outer edges. Both within and outside of the mapped area, the red scoria trends in a northeast-southwest direction inside the structural zone.

The great thickness of basaltic rocks, abundant red (oxidized) scoria, and a "dike-like" geometry to the El Porticito outcrop all suggest that the northeast trending structural zone (best exposed near Mesa Tinaja) is also a vent zone for the Tejana Mesa basalts (Plate 1). Red scoria is typical of vent areas (Cima, 1978). Although shown on the geologic map as a graben-like feature, the greater thickness of basalts along the southeast flank of Tejana Mesa could be related to explosive (phreatic) cratering along the intrusive trend where it crossed a water-saturated channel zone. The northwesterly elongation of Tejana Mesa probably reflects eruption into a northwestward trending Fence Lake paleochannel.

The transition zone from the basalt flows to the underlying Fence Lake Formation is interpreted to represent the initiation of local volcanism. The scoria in the conglomerates were probably derived by air-fall from early pyroclastic eruptions along the vent zone at Tejana Mesa. Though the contact between the Fence Lake Formation and the transition zone is largely covered, it is inferred to be conformable. Near the top of the transition zone, bedded cinder units are locally interbedded with sandstones and conglomerates. The uppermost 3 to 10 feet of the transition zone are typically composed entirely of air-fall deposits (cinder size) which indicate a complete overwhelming of earlier fluvial activity.

Three possible reasons for the great thickness of basalts capping Mesa Tinaja are: 1) the basalt flows filled a depression within the Fence Lake Formation, 2) the basalt is a volcanic neck previously enclosed within the Fence Lake Formation, and 3) the basalt is a plug (lava lake) that was originally surrounded by a pyroclastic cone built up on top of the Fence Lake Formation. The third hypothesis is believed to the most viable, because the other two hypotheses would require a much greater thickness of Fence Lake Formation (approximately 400 feet) than is known to presently exist in the TM-HD area or at its type section (220 feet).

Older Quaternary-Tertiary Basalts

Quaternary-Tertiary old basalts (QTob), as mapped here, are found as remnants of a flow (or flows?) on the northeast and northwest sides of Mesa Tinaja. They also cap a small mesa located just south of Mesa Tinaja.

The "QTob" flows are petrographically indistinguishable from the lavas found on Tejana Mesa and Mesa Tinaja. The "QTob" flows are porphyritic olivine-augite basalts with phenocrysts of olivine and pyroxene. The olivine often shows alteration to yellow-brown iddingsite. The micro-crystalline matrix contains augite, magnetite, and feldspar. The basalts contain xenoliths of dunite/peridotite.

The "QTob" basalts on the mesa south of Mesa Tinaja ("southern mesa") are 60 feet thick and consist of two flows separated by a flow-breccia zone. The lower flow is about five feet thick and the upper flow is about 50 feet thick. A feeder dike and vent relationship is exposed on the northern portion of the "southern mesa" (Plate 1). The lower flow lies directly on about 80 feet of Fence Lake Formation. On the northeast side of Mesa Tinaja, the "QTob" basalts rest directly on the Baca Formation, and on the northwest side they rest partly on Baca Formation and partly on Fence Lake Formation. Breccias associated with both these basalt outcrops, similar in appearence to vent breccias at the top of the dike feeding the "southern mesa" flow (see Basalt Dikes section), indicate the possible existence of additional volcanic vents for the QTob flows.

The older Quaternary-Tertiary basalts are believed to be a distinctly younger unit than the "Basalt of Tejana Mesa" for two reasons. First, the "QTob" flows are not underlain by the fluvial-pyroclastic transition zone or by as great a thickness of Fence Lake Formation that underlies the basalt flows both on Tejana Mesa and on nearby Mesa Tinaja. Secondly, a separate feeder dike exists for the southern "QTob" flow, which would allow a multiple flow relationship. This is considered to be permissive but not compelling evidence that the "QTob" basalts are younger flows than the "Basalt of Tejana Mesa".

The older Quaternary-Tertiary basalts were apparently extruded after erosion had cut through portions of the Fence Lake Formation, the Baca Formation, and part of the "QTbt" in the vicinity of Mesa Tinaja. The basalts were extruded onto a surface comprised of both the Baca and Fence Lake Formations. The "QTob" basalts were erupted from the vent on the "southern mesa" and possibly from vents(?) located on the northeast and northwest sides of Mesa Tinaja. Subsequent erosion removed all portions of these flows except those inset against Mesa Tinaja and those capping the "southern" mesa..

The feeder dike for the "QTob" basalts strikes northeast, parallel to the structural/vent zone of the "Basalt of Tejana Mesa". The older Quaternary-Tertiary basalts may represent reactivation of the Tejana Mesa fault/vent zone.

Basalt Dikes

Dikes in the mapped area consist of porphyritic olivine-augite basalts which served as feeders to the "Basalt of Tejana Mesa" and to the older Quaternary-Tertiary basalts. There are no outcrops of feeder dikes to the younger Quaternary-Tertiary basalts. Most of the dikes are exposed in the vicinity of Mesa Tinaja. One dike is also exposed near the vent zone on the southeast flank of Tejana Mesa. All dikes generally strike northeasterly, have near vertical dips, and range in thickness from 0.5 to 10 feet. The dikes become brecciated in appearance and widen considerably as they approach the paleosurface marked by the associated lava flows. The small mesa, south of Mesa Tinaja, has a well exposed vent breccia at the top of the dike. The breccia is yellow brown in color and is composed of fragments of sandstone and basalt cemented by coarsly-crystalline calcite.

Bidahochi(?) Formation

The name Bidahochi Formation was given by Reagan (1924) to a sequence of sandstones, shales, tuffs, and basaltic lavas located at the Hopi Buttes in northeastern Arizona. The Bidahochi Formation has since been subdivided into three members: a lower lacustrine member, a medial volcanic member, and an upper fluvial member (Repenning and Halpenny, 1951; Repenning and Irwin, 1954). A K-Ar date of 6.69 +/- 0.16 m.y. from a trachybasalt of the middle volcanic member (Scarborough and others, 1974) is consistent with fossil evidence that demonstrates a late Miocene age for the lower two members of the Bidahochi Formation. Fossilized camel bone fragments from the upper fluvial member suggest a Pliocene age for portions of this member (Repenning and others, 1958).

The Bidahochi Formation forms discontinuous exposures in northeastern Arizona and in portions of northwestern New Mexico. It rests unconformably on sedimentary rocks ranging in age from Paleozoic to middle Cenozoic. The upper contact of the Bidahochi Formation is largely an eroded surface, but at a few localities, such as the west flank of the Zuni and Defiance upwarps and north of White Cone, Arizona, the upper member of the Bidahochi Formation appears to be conformably overlain by middle Pleistocene (or younger) sandy soils and dunes (Repenning and others, 1958).

The Bidahochi Formation was deposited in the Black Mesa Basin, which is an exhumed (rejuvenated ?) Laramide basin. Sediments of the upper member were supplied to the basin by way of two major stream courses. One flowed southwest into the basin around the southern nose of the Defiance upwarp and the other flowed northwest into the basin along the Ancestral Carrizo Wash (see fig. 14). Repenning and others (1958) noted the presence of abundant rhyolitic debris in the upper member (south of the Carrizo Wash), which they interpreted as derived from the Datil volcanic field located to the south and southeast. The TM-HD area is located along the northern margin of the Ancestral Carrizo Wash (see Fig. 14).

The Bidahochi(?) Formation, as tentatively correlated in the TM-HD area, consists of a single exposure located in a topographic saddle between Tejana Mesa and Mesa Tinaja. The circular outcrop pattern is caused by erosional truncation (to the north and south) of what is clearly a northwest trending paleovalley fill (see Plate 1, cross-section B-B"). The lower contact in the paleovalley cuts across the Fence Lake Formation, the Baca Formation, and locally into the Mesaverde Group at its deepest point. The formation has an upper erosional surface. The maximum exposed thickness of the Bidahochi(?) Formation is about 260 feet.

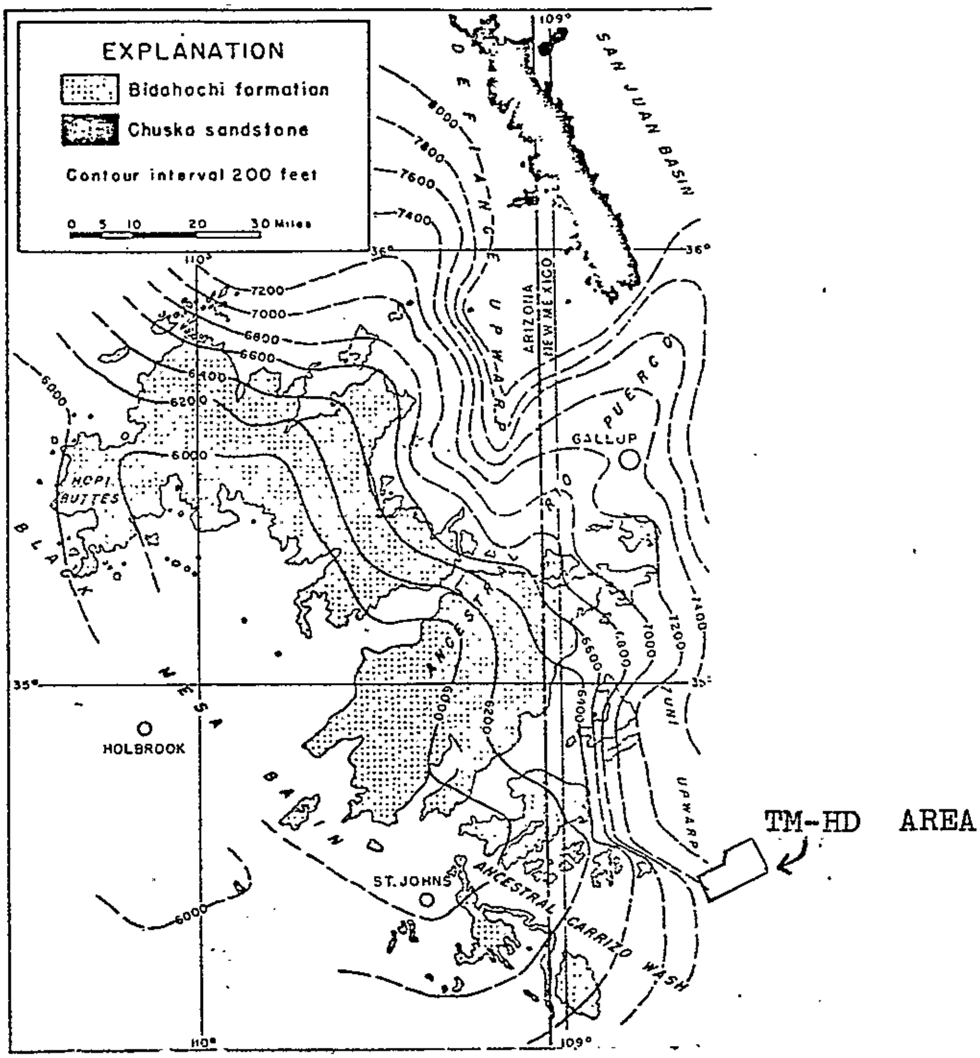


Figure 14. Map showing the location of the TM-HD area relative to the Ancestral Carrizo Wash. Contours show modern altitude above sea level of the depositional surface of the Bidahochi. The contours have not been corrected for post-Bidahochi deformation (from Repenning and others, 1958).

The Bidahochi(?) conglomerates contain granule to pebble-sized, subspherical clasts of basaltic scoria, granule to boulder sized basaltic lava, and granule to pebble sized sandstone and sandy limestone. Rare pebbles of well-rounded quartzite and angular micrite were also observed. Scoria-rich conglomerates are found in both the upper and lower portions of the formation. These contain occasional pebbles and cobbles of spheroidal basalt. Lenticular beds of cinders exhibiting graded bedding, up to about two feet in thickness, are found within the lower conglomerate.

The bulk of the Bidahochi(?) Formation consists of sandstones and conglomeratic sandstones with matrix supported clasts. Cut and fill channels, 10 to 15 feet wide and about one foot deep, are common in the conglomeratic sandstones. A thin-section of the sandstone (TM-215) was found to be a fine-grained, poorly sorted, lithic arkose (McBride classification, 1963) that consists of about 40 percent calcite cement. The thin section contains abundant basaltic and rhyodacitic lithic fragments, and minor rhyolitic fragments. A few 5-to 25-foot thick beds of laterally discontinuous, dark-reddish-maroon, mudstones and claystones are interbedded with the sandstones. At least two beds, each about one foot thick, of white, sandy limestone are interbedded within the formation.

This sedimentary map unit is tentatively correlated to the upper (fluvial) member of the Bidahochi Formation. The possible correlation of the Fence Lake Formation with the lower member of the Bidahochi Formation was discussed previously. The paleovalley, which the Bidahochi(?) sediments backfilled, must have cut about 450 feet below the surface on which the Basalt of Tejana Mesa was erupted.

The Bidahochi(?) Formation is interpreted to have been deposited in the paleovalley by northwesterly flowing streams, probably braided. This is consistent with the work of Repenning and others (1958) who report the deposition of the upper member of the Bidahochi Formation by northwesterly flowing streams in the nearby Ancestral Carrizo Wash (see fig. 14). The sandy limestone units, interbedded in the Bidahochi(?) beds, are interpreted as pedocalcic soil horizons and therefore indicate at least two periods of soil development in a semi-arid climate, during deposition of the Bidahochi(?) Formation.

Dark-reddish-maroon mudstones and claystones interbedded in the Bidahochi(?) Formation were probably reworked from the underlying Baca Formation. The relatively abundant quartz in the Bidahochi(?) sandstones (compared to Fence Lake sandstones) is believed to have been derived from sandstones of the Baca Formation.

Volcanism accompanied at least the initial stages of valley filling as indicated by the basalt flows and bedded cinders near the base of the formation. Scoria clasts in the Bidahochi(?) conglomerates probably represent penecontemporaneous pyroclastic volcanism. Spheroidal masses of basalt in the scoria beds probably represent volcanic bombs from vents presumably buried under valley-fill along the Tejana Mesa fault zone. Sources for other basaltic lithic fragments in the Bidahochi(?) could be the "Basalt of Tejana Mesa" and clasts reworked from the Fence Lake Formation. The eroded margin of the Datil-Mogollon volcanic field, south of the TM-HD area, is interpreted to have been the source for the wide variety of rhyolitic volcanic clasts (Repenning and others, 1958). This is consistent with the northwesterly flowing fluvial systems that deposited the Bidahochi Formation.

<u>Younger Quaternary-Tertiary Basalts</u>. The younger Quaternary-Tertiary basalts are interbedded in the basal portion of the Bidahochi(?) Formation. The basalts are found along portions of both the northwestern and southern margins of the Bidahochi(?) outcrop. The flows are porphyritic olivine-augite basalts with phenocrysts of olivine and pyroxene. The olivine often shows alteration to yellow-brown iddingsite. The micro-crystalline matrix contains augite, feldspar, intergranular pyroxene and magnetite. The flows contain rare xenoliths of dunite/peridotite. The basalt along the northwestern margin

contains abundant olivine phenocrysts while the basalt along the southern margin contains significantly fewer olivine phenocrysts. The flow at the northwestern margin is underlain by flow breccia.

Quaternary Deposits

Talus. Talus deposits are found locally on the flanks of mesas within the TM-HD area. Basaltic blocks derived from mesa-capping flows, or basalt boulders derived from the Fence Lake conglomerates, comprise most of the talus deposits.

Landslide Block. A single toreva-type landslide block is located on the east side of Mesa Tinaja. The block was apparently derived from the basal portion of the mesa capping basalts (QTbt). A vertical scar left in the wake of the landslide has not yet been oxidized by surface weathering. Therefore, the landslide probably occurred in the Holocene.

Alluvium. Alluvial deposits which consist of unconsolidated sand, gravel, and mud, fill broad valleys and low flat areas between hill slopes. The alluvial surfaces grade to modern draws (Hubbell, Sonoreno, Lopez, Tejana) or to low terraces along draws. The alluvial deposits are considered to be late Pleistocene to Holocene in age.

STRUCTURAL GEOLOGY

Regional Setting

The TM-HD area is located on the Mogollon slope, which forms the southern margin of the Colorado Plateau (Kelly and Clinton, 1960), and along the northern eroded margin of the Datil-Mogollon volcanic field. The major structural features of west-central New Mexico are shown in figure 15.

The structural geology of west-central New Mexico has been dominated by Laramide compression and late Cenozoic extension. Laramide features shown in figure 15 include the Gallup sag, the Acoma sag, and the Morenci uplift. Uplift of the Zuni Mountains, which began in the Laramide (Hunt, 1956), is probably still occurring (C. T. Smith, oral commun., 1982). The downwarps of the Acoma sag and the Gallup sag are defined by monoclines. A broad "synclinal horst" (Wengerd, 1959) trends south-southwest from the Acoma sag and plunges under the Datil Mountains. This horst is bounded by the Red Lake and Hickman fault zones. These fault zones may have once been reverse faults (Laramide), associated with the development of the syncline, which have been reactivated as normal faults during late Cenozoic extension (Chamberlin, 1981). In the Datil area, folds and associated high-angle faults, developed within the Mesaverde Group, have been locally truncated or buried by an erosional unconformity at the base of the Eocene Baca Formation (Chamberlin, 1981).

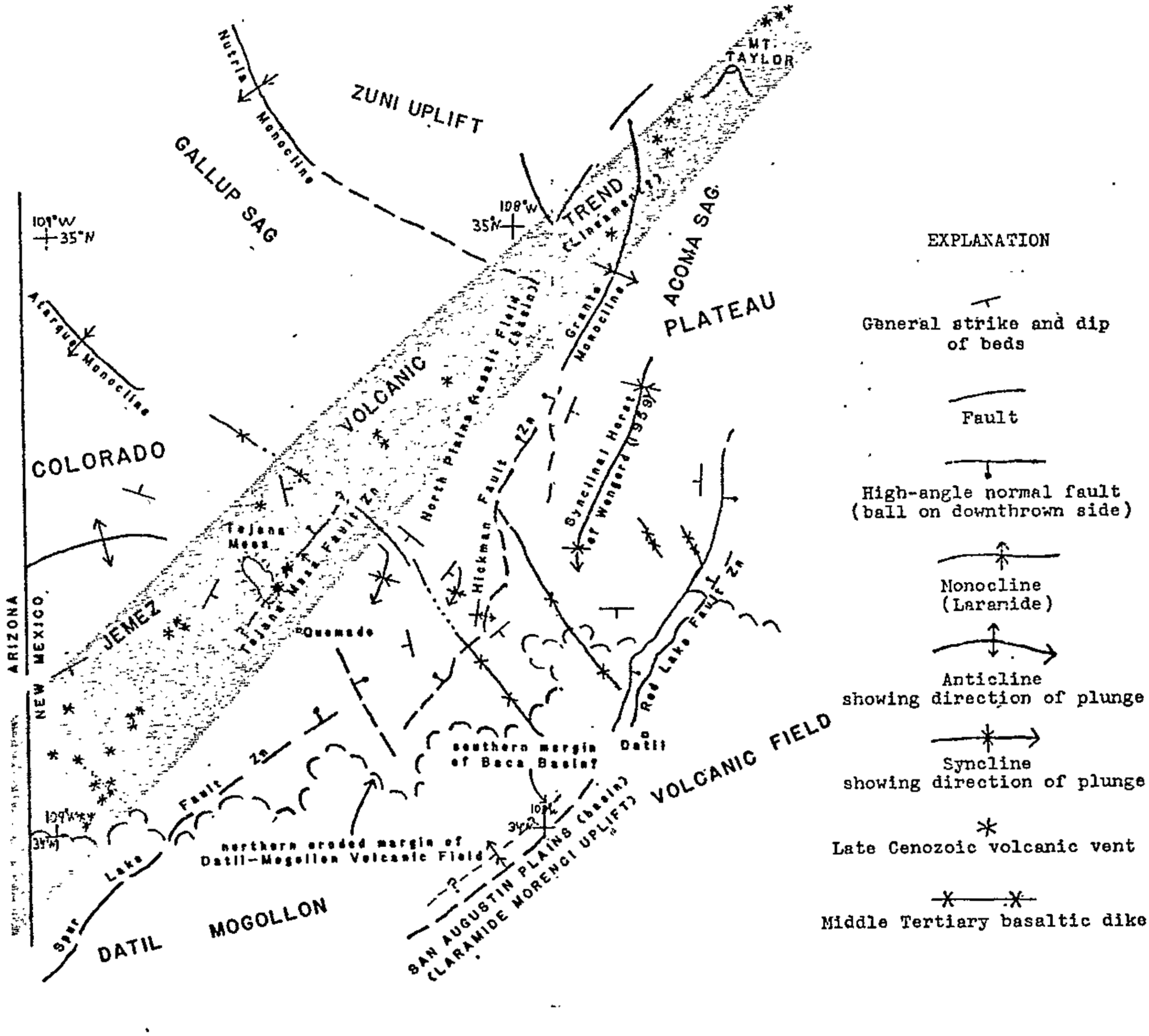


Figure 15. Major structural features of west-central New Mexico. Base map from Dane and Bachman, 1965. Other sources: Wengerd (1959), Laughlin and others, 1979 (Jemez lineament), Chamberlin (1981), Chapin and Cather (1981), Chamberlin (oral commun., 1982).

Crustal extension began in the late Oligocene with the emplacement (near Pietown, NM) of long, northwest trending basaltic andesite(?) dikes that have been dated at 27.7 m.y. (Laughlin and others, 1979). Subsequent to dike emplacement, a gentle south-southwestward tilt of Cretaceous and Tertiary strata was developed in the Datil Mountains area in late Cenozoic time. This southward tilting is attributed to relatively minor extension and sagging of the Colorado Plateau margin, in association with the San Augustin arm of the Rio Grande rift (Chamberlin, 1981). The Jemez volcanic trend (lineament) reflects the latest period of crustal extension and is defined by a northeast-trending belt of predominantly mafic volcanic fields ranging in age from Miocene to Holocene (Laughlin and others, 1978; Chapin and others, 1978).

Local Structure

There are two dominant structural trends within the TM-HD area. One of these is an overall, gentle southeastward tilt of the Mesaverde Group, Baca Formation, and Spears Formation. The other structural feature is a northeasterly trending zone of high-angle normal faults and dikes.

Attitude data from the Mesaverde Group, Baca Formation, and Spears Formation indicate an overall, gentle (1-3 degrees) southeastward tilt of these units. Subsequent to tilting, both the Baca and Spears formations were erosionally thinned and removed (toward the northwest) beneath the unconformity at the base of the Fence Lake Formation. The northwestward erosional thinning of the Baca Formation is demonstrated along the flank of Tejana Mesa (see cross-section A-A′ on Plate 1). From Mariano Mesa northwest to the unnamed mesa northeast of Hubbell Draw (fig. 2), the 1050-foot-thick Baca/Spears section thins to 250 feet of Baca Formation beneath the basal Fence Lake unconformity.

The locations of the faults and dikes of the TM-HD area are shown on figure 16. All of the faults are normal. Slickensides observed on one fault indicate dip slip movement at a dip of 64 degrees. Field observations and surface trends of the faults indicate that they are all high angle (dips of 60-90 degrees). All of the dikes are nearly vertical.

A through-going, northeasterly trending structural zone transects the TM-HD area. This zone will be referred to as the Tejana Mesa fault zone (fig. 16). Beginning at Tejana Mesa, the zone is expressed as a graben that may contain a number of volcanic vents as indicated by an abundance of altered (red) scoria (Cima, 1978). The structural zone steps over in a left lateral sense to the northwest in the vicinity of Mesa Tinaja. This "offset" is accommodated by a poorly exposed monoclinal flexure (west facing), which

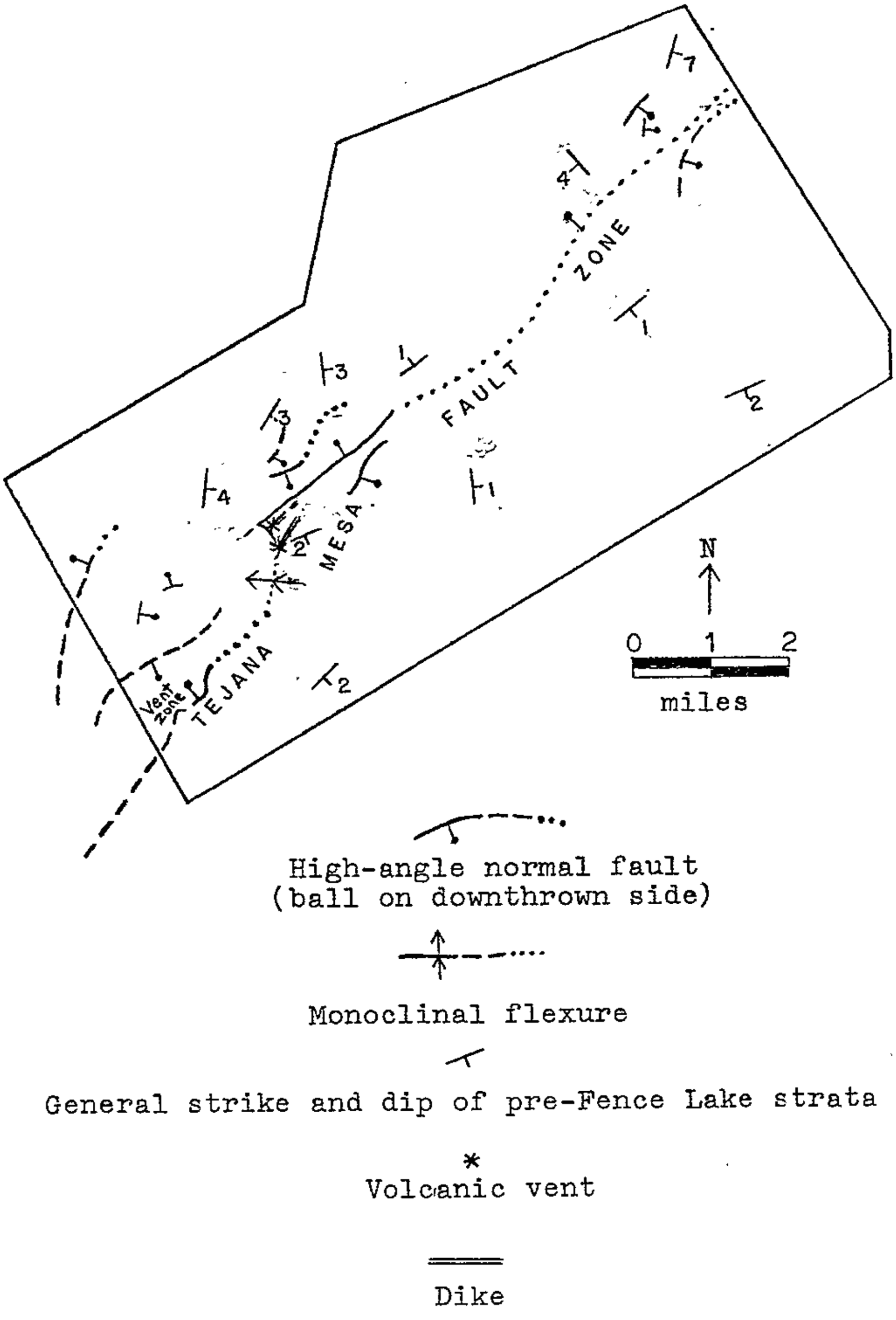


Figure 16. Structural index map of the TM-HD area showing major faults and dikes.

connects the southern faults of the grabens located at Tejana Mesa and northeast of Mesa Tinaja. Northeast trending dikes are associated with the fault zone near Mesa Tinaja. The Baca Formation has been down-dropped approximately 250 feet in the graben northeast of Mesa Tinaja (see fig. D-D′ on Plate 1). The southern master fault of this graben, which cuts across the entire mapped area (see cross sections of Plate 1), has a maximum stratigraphic throw of at least 250 feet.

The late Cenozoic extensional features just described, are the only kinds of deformation apparent in the TM-HD area. Laramide folding is not evident in the gently dipping beds of the Mesaverde Group, but could be masked by late Cenozoic extensional features. All faulting in the TM-HD area post dates the Fence Lake Formation.

The gentle southeastward tilt of the Late Cretaceous-early Tertiary section was the first of the two dominant structural trends to be developed in the TM-HD area. This tilting (late Oligocene-early Miocene) may have been the result of minor extension and sagging of the Colorado Plateau margin (see Chamberlin, 1981). Northwestward flowing streams, off of the topographically high Datil Mogollon volcanic field, both thinned and removed portions of the upturned early Tertiary section (eg. Baca and Spears Formations). These northwestward flowing streams then backfilled and deposited the Fence Lake Formation onto the erosion surface underlain by the Baca and Spears formations.

The development of the second dominant structural feature of the TM-HD area was marked by the extrusion of the "Basalt of Tejana Mesa" (late Miocene?-Pliocene?) from a northeastward-trending zone of structural weakness (Tejana Mesa fault zone). This zone is approximately at a 90 degree angle to an earlier northwest trending zone of structural weakness (located just northeast of the TM-HD area) defined by a late Oligocene dike system (see fig. 15). Both of these features may be a reflection of deep-seated basement structures upon which only minor changes in the direction of extension could have accounted for activation of one trend in preference to the other. Alternatively, one or both of these dike trends may have been the result of extension produced at a high angle to a northerly directed compressional stress. Some structures in west-central New Mexico such as the Naciemento thrust, have been interpreted as related to local zones of compression (Kelly, 1950).

The history of faulting along the Tejana Mesa fault zone began with the development of a graben-like structure on the southeast flank of what is now Tejana Mesa. At least 360 feet of basalt and scoria accumulated in this graben-like vent zone. As discussed previously (in the "Basalt of Tejana Mesa" section), this great thickness of volcanic material could be related to explosive (phreatic) cratering along the intrusive trend where it crossed a water-saturated channel zone. Most of the faulting in the TM-HD area is believed to have occurred after extrusion of the "Basalt of Tejana Mesa" and some may have occurred even after deposition of the Bidahochi(?) Formation. The master fault of the Tejana Mesa fault zone dies out at Mesa Tinaja as a monoclinal flexure of the Basalt of Tejana Mesa and older formations. Post-Bidahochi(?) Formation tensional deformation is indicated by a 45 degree tilt of the Bidahochi(?) Formation, along its northern outcrop margin, which is interpreted to be the result of downwarping (graben development) along the Tejana Mesa fault zone.

The northeast trend of the vents, dikes, and faults in the TM-HD area is both parallel to, and on line with (fig. 15), the Jemez volcanic trend/lineament (see fig. 1 of Chapin and others, 1978; Laughlin and others, 1978). The Tejana Mesa fault zone and the basalt volcanism of the TM-HD area are therefore interpreted to be part of the Jemez lineament.

URANIUM GEOLOGY

There are two known uranium occurrences in the TM-HD area. These are the Varnum deposit (minor production) and the Mangum prospect (no production). The approximate location of these occurrences and other radiometric anomalies detected within the TM-HD area have been plotted on Plate 1. The background radiation in the TM-HD area ranges from 20 to 50 cps (counts per second of total gamma radiation). Radiometric anomalies detected in the field area range from 120 to 1400 cps.

The Varnum deposit is located in the center W1/2 W1/2 NE1/4 sec. 21, T.3N., R.16W. and is reported in Hilpert (1969) as occurring in a sandstone of the Mesaverde Group. The only production from the deposit was during the 1950´s when five pounds of uranium oxide were produced from 12 tons of ore at an average grade of 0.02% U3O8 (Barnes, 1960). The Varnum deposit is discussed in May and others (1980), who reported it to occur in the Baca Formation.

Results of this study show that the Varnum deposit is located within the Mesaverde Group, below the pre-Baca, post-Mesaverde oxidation zone. One shallow pit was observed at the reported location (presumed to be the area of production). This pit is in a fine-grained sandstone that is grayish yellow (5Y 8/4) speckled with white. Only one radiometric anomaly of 300 cps was found near the pit. Elsewhere in the general vicinity of the deposit, anomalies of 460 cps and 500 cps were found at the base of the pre-Baca oxidation zone (see Plate 1).

The Mangum prospect is located in the S1/2 sec. 22, T.3N., R.16W. Hilpert (1969) reports the prospect as being in the Mesaverde Group. There has been no production from this prospect (May and others, 1980). No workings were observed, but anomalous radioactivity was detected at the base of the pre-Baca oxidation zone (see Plate 1) in the vicinity of the location reported in Hilpert (1969). The highest radioactivity (1400 cps) is associated with a sandstone outcrop (near the top of an old wooden chute), which contains abundant carbonaceous debris and exhibits limonite staining.

All of the radiometric anomalies in the Mesaverde Group are found in two clusters near the two known uranium occurrences. These anomalies are at, or near, the base of the pre-Baca oxidation zone. None of the steeply dipping ("C"-shaped) alteration fronts that cut across bedding at the base of the oxidation zone are radioactive. A single weak radiometric anomaly (150 cps) was found in a red sandstone of the Baca Formation. The radioactivity in the Baca Formation seems to be associated with thin (less than 1 mm) dark colored bands of iron oxides(?) within the sandstone (similar to Baca occurrences in the Datil Mountains; Chamberlin, 1981). No anomalous radioactivity was detected from any of the other units of the TM-HD area.

Numerous other uranium occurrences are reported in the rocks of the Baca Formation and the Mesaverde Group east of the TM-HD area. In the Baca Formation, these include the Hook ranch prospect in the Gallinas Mountains area (Cather, 1980) and three minor occurrences in Baca Canyon (Potter, 1970). In the Datil Mountains area, both the Red Basin mine and the McPhaul adit deposit are found at the base of the pre-Baca oxidation zone and the Midnight 2 mine is located in the Crevasse Canyon rocks below the altered zone (Chamberlin, 1981). In addition, an apparently continuous radiometric anomaly (120-200 cps) is present at essentially all exposures of the base of the altered zone in the Alamocito Creek area (Chamberlin, 1981).

A number of hypotheses for the genesis of the uranium deposits in the Datil Mountains have been presented in the literature. Uranium occurrences in both the Datil area and the TM-HD area were probably formed by the same processes since both areas have the same stratigraphic sequence and similar patterns of uranium mineralization. Two sources of uranium for the occurrences in the Baca Formation and the Mesaverde Group of west-central New Mexico are considered: 1) the tuffs of the Datil-Mogollon volcanic field (Oligocene), and 2) carbon-rich sediments of the Mesaverde Group.

One of the initial theories of ore genesis for the deposits in the Datil area was that uranium was precipitated from descending meteoric water that had leached uranium from the siliceous rocks of the Datil volcanics that overlie the Baca Formation (Griggs, 1954). Galloway (1978) has found considerable evidence for a tuff source of uranium for the deposits of the Tertiary Catahoula Formation of South Texas. Walton and others (1981) have shown that uranium is released from volcanic glass, in sedimentary sequences, by a complete dissolution of the glass during pedogenic alteration. This process releases uranium for long distance migration and ore formation. Alteration of tuffs by later ground water flow apparently produces only local redistribution of uranium. Therefore, if the tuffs of the Datil volcanics were the uranium source for the deposits in the Baca Formation and Mesaverde Group, then this would probably have required syndepositional pedogenesis of the tuffs in Oligocene time.

It is unlikely that the tuffs of the Datil Group were a uranium source for occurrences at the base of the pre-Baca alteration zone, for a number of reasons. First of all, no paleosols (weathering profiles) have been observed or reported in the Oligocene volcanic sequence of the Datil-Quemado area (Chamberlin, oral communication, 1982). Even if uranium had been released from the tuffs, it would be unlikely for uranium-bearing solutions (presumably alkaline and oxidizing) to pass through the entire Baca Formation and the pre-Baca oxidation zone to form deposits at the base of the oxidation zone. The thickness of the Baca Formation averages 600 feet with a maximum thickness of 2500 feet (Snyder, 1971). Since the Eh of ground water generally decreases with depth below the water table (Levinson, 1974), deep ground waters would be a less likely media for uranium transport, which requires oxidized conditions to remain in solution (Hostetler and Garrels, 1962). In addition, the rate of ground water flow generally decreases with depth, which would tend to disfavor ore formation at greater depth.

The carbonaceous mudstones of the Mesaverde Group have been proposed as a uranium source (Chamberlin, 1981). As mentioned previously, in the Mesaverde Group section, the sediments of the Mesaverde Group were derived from a granitic terrain. It is quite possible that uranium was released from granitic rocks during erosion, was transported in solution by the surface waters (Langford, 1977) that deposited the Mesaverde Group, and was then syngenetically or diagenetically concentrated as protore accumulations in the carbonaceous mudstones of the Mesaverde Group.

Chamberlin (1981) has shown that a number of uranium deposits in the Datil Mountains area are spatially associated with the base of a pre-Baca, post-Mesaverde alteration zone and states that the base of this zone coincides with an almost continuous band of radiometric anomalies. He interprets the alteration zone as the "C" horizon of a lateritic paleosol, and that uranium was leached from uraniferous shales (carbonaceous) of the Mesaverde Group (possibly averaging 10 ppm U3O8) by organic-rich acidic solutions during the soil-forming process. The uranium was then redeposited in a more concentrated form at redox boundaries between actively flowing and relatively stagnant ground waters. Deposition occurred in the form of tabular (tails of roll fronts ?) and roll-front deposits (lateral to the lenticular channel sands). According to this model, uranium occurrences in the Baca Formation may have been, in part, derived from erosion of the uranium-rich lateritic soil from uplifts and basin margins, which would have flushed uranium-rich waters into the Baca Basin.

The radiometric anomalies in the TM-HD area are all located (except for one occurrence in the Baca Formation) at or near the base of the pre-Baca alteration zone. Since this alteration zone is believed to be a continuation of the lateritic paleosol exposed in the Datil Mountains area (see Post-Mesaverde, pre-Baca Oxidation Zone section), the pedogenic/supergene interpretation of Chamberlin (1981) for the genesis of uranium mineralization is believed to be the most likely model to explain the uranium occurrences in the TM-HD area.

There is a significant difference between the TM-HD area and the Datil Mountains area in the intensity and frequency of radiometric anomalies at the base of the pre-Baca alteration zone. Anomalies in the TM-HD area are relatively weak in intensity and fewer in number. Since the same process is thought to have been responsible for uranium mineralization at both areas, the differences may be attributed to: 1) a greater degree of recent weathering of the favorable horizon in the TM-HD area (steep-sided mesas and canyons in the Datil Mountains area are indicative of active erosion), 2) original (protore) accumulation of uranium in mudstones of the Mesaverde Group may have been less in the TM-HD area (no data), 3) the pedogenic alteration in the TM-HD area may not have been intense enough (eg. sufficiently oxidizing and acidic) to leach significant quantities of uranium from the carbonaceous mudstone protore. Both the destruction of carbonaceous debris and the leaching of carbonate, by tropical weathering, was apparently less complete in the paleosol of the TM-HD area. This is evidenced by the presence of carbonaceous mudstones and well-indurated calcareous sandstones near the top of the paleosol in the TM-HD area.

URANIUM POTENTIAL

The post-Mesaverde, pre-Baca oxidation zone is interpreted to be the primary zone of uranium potential in the TM-HD area for two reasons: 1) the tropical pedogenesis, inferred to have produced the oxidation zone (paleosol) provides a viable mechanism for the formation of tabular and roll front ore deposits in this region (see Chamberlin, 1981), and 2) there are a number of known uranium occurrences (seven radiometric anomalies and one small deposit) associated with the redox boundary at the base of the oxidation zone. In addition to the redox boundary, the unalterd (reduced) sandstones within the oxidation zone are also favorable sites for ore deposition. On the basis of typical sandstone thicknesses of the unaltered and oxidized Mesaverde beds, the average potential thickness of roll front deposits would be 10 to 15 feet with maximum thicknesses of up to 35 feet. The paleosol provides a shallow uranium exploration target in the TM-HD area (see fig. 17). Since the paleosol dips gently to the south-southeast, additional shallow exploration targets (<1000 feet deep) are present in this direction. Assuming a one degree regional dip, the base of the paleosol would project 1000 feet below its outcrop elevation at a distance of about 10 miles south-southeast of the southern margin of the mapped area.

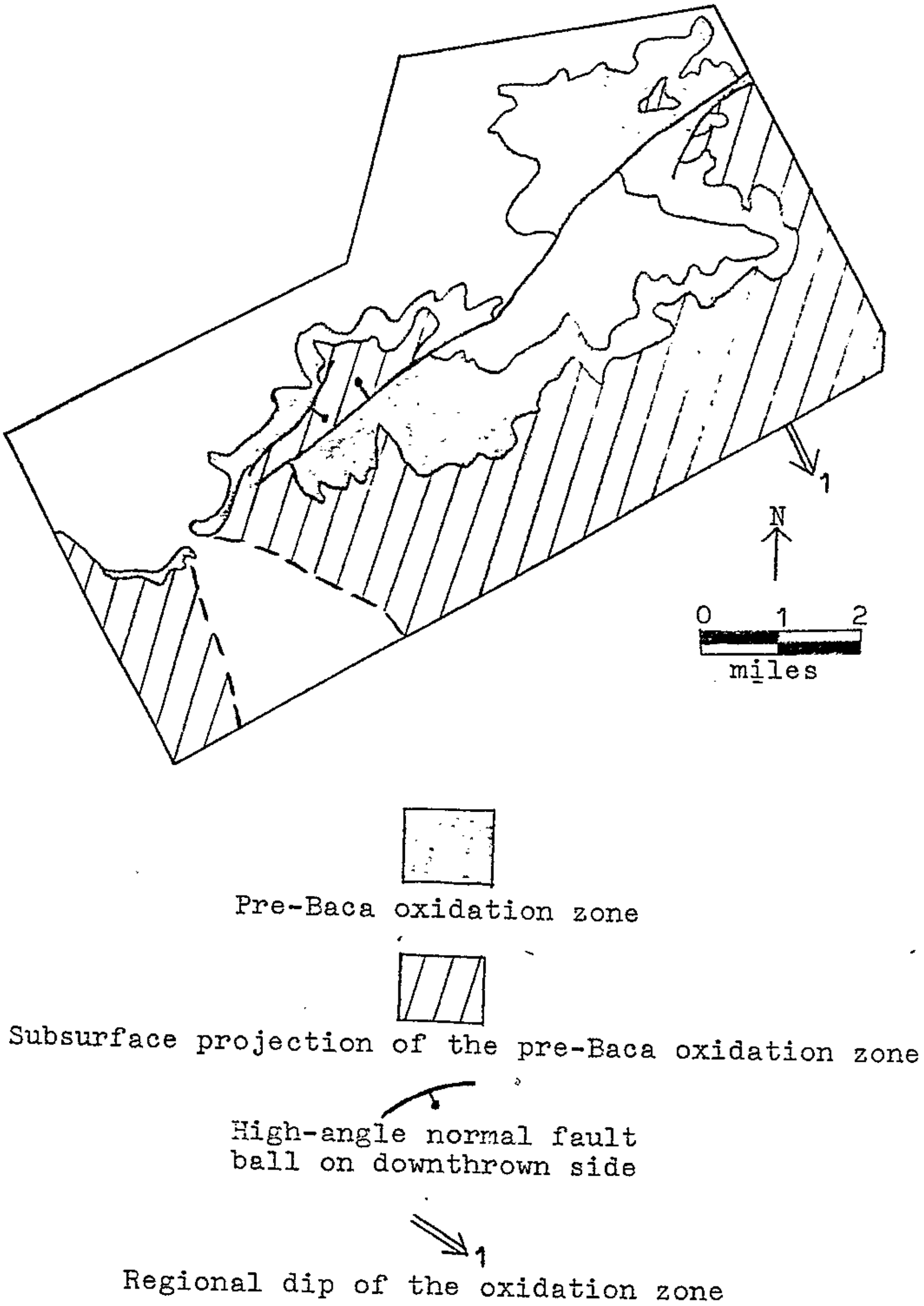


Figure 17. Surface and subsurface locations of the pre-Baca oxidation zone in the TM-HD area.

In the Datil Mountains, "C"-shaped alteration fronts exposed at the base of the pre-Baca weathering profile are commonly radioactive, verified as uranium bearing, and sharply defined by greenish-gray chlorite bands (Chamberlin, 1981). These characteristics, interpreted as features of leached uranium roll fronts, have not been observed in "C"-shaped fronts at the base of the pre-Baca oxidation zone in the TM-HD area (fig. 3). Until reasons for this difference can be explained, it will be presumed that the probability for discovery of uranium-roll-front deposits in the subsurface of the TM-HD area is less than that of the Datil Mountains area.

In any future exploratory drilling of the TM-HD area, or regions to the southeast, the author suggests that at least one drill hole penetrate a minimum of 100 feet of unaltered Mesaverde beds below the oxidation zone. By sampling unaltered mudstones below the oxidation zone, one could deduce whether or not there was enough of a syngenetic (protore) uranium concentration in the mudstones of the paleosol to have provided a sufficient source of uranium for ore formation by the proposed pedogenic model (Chamberlin, 1981).

The uranium potential of the Baca Formation is uncertain. Baca sandstones are good aquifers. Most of these sandstones are very pale orange (10YR 8/2) to pale yellowish orange (10YR 8/6) in color (bleached ?), which suggests that they may be chemically reduced in subsurface. Baca sandstones may therefore be chemically suitable hosts for uranium mineralization. As stated previously, the most likely uranium source for such possible mineralization would be from erosion of the uranium-rich lateritic soil from uplifts and basin margins, which would have flushed uranium-rich waters into the Baca Basin.

GEOLOGIC HISTORY

The geologic history of the units exposed in the Tejana Mesa-Hubbell Draw area began with deposition of sediments of the Mesaverde Group. The Mesaverde beds were deposited in a fluvial/paludal environment during the Late Cretaceous. Sedimentary transport directions were generally to the north-northeast toward the Cretaceous epeiric sea. Sediments were derived from a granitic terrain with a minor andesitic lava component. The depositional environment contained abundant vegetation as indicated by concentrations of carbonaceous debris in the sandstones and by the presence of carbonaceous mudstones. Pollens and spores from one of these mudstones indicate a subtropical to warm temperate climate.

The time interval between deposition of the Late Cretaceous sediments of the Mesaverde Group and those of the Eocene Baca Formation was marked by the development of a wet climate (pedalfer) weathering profile on the Mesaverde beds. This soil development probably took place during a possible late Paleocene-middle Eocene period of inter-Laramide quiescence. Hematite-limonite pebbles found at the base of the Baca Formaton were probably derived from erosion of an ironstone cap on the weathering profile. This evidence of an iron-rich zone at the top of the profile together with the great thickness of the weathered zone (up to 160 ft) suggests that the soil type was of a lateritic character.

The Baca Formation was deposited by fluvial processes onto a low-relief erosional surface on the paleosol. The change in climate to semi-arid conditions is demonstrated by the pedocal soil horizons observed in some of the interfluvial mudstone units near the base of the Baca Formation. Sedimentary transport directions were generally to the east with the sediments being derived from the Mogollon Highland of Arizona.

Volcanic sediments of the Spears Formation (early Oligocene) were deposited conformably on the Baca Formation. Since the maximum preserved thickness of the Spears Formation is 520 feet at Mariano Mesa, this unit is interpreted to have once covered the entire TM-HD area. The most common volcanic clast of the Spears rocks is rhyodacite/latite porphyry.

Extensional tectonics began in the region in the late Oligocene as evidenced by a northwest trending dike system (27.7 m.y.) located just northeast of the TM-HD area. Subsequent to dike intrusion, there was a gentle (one to three degrees) southeastward tilting (late Oligocene-Miocene) of the Spears and older formations. This tilting was probably the result of minor extension and sagging of the Colorado Plateau margin.

Subsequent to tilting, the older formations were beveled by a northwest-facing erosion surface cut by streams flowing off the topographically high Datil Mogollon volcanic field. These streams removed most of the Spears Formation in the TM-HD area, thinned the Baca Formation to the northwest, and later deposited the Fence Lake Formation (Miocene). In the TM-HD area, the Fence Lake Formation is composed of sand to boulder sized fragments of rhyodacite/latite from the Spears Formation, and sand to boulder sized fragments of basaltic lava derived from the Mangas Mountains, located about 25 miles to the southeast, and/or from basalt flows associated with the late Oligocene dike system.

The "Basalt of Tejana Mesa" (late Miocene?-early Pliocene?) was extruded onto the Fence Lake Formation from a northeast trending zone of structural weakness. The orientation of this zone is demonstrated by the alignment of oxidized vent areas and dikes. The structural zone and associated volcanics are probably part of the Jemez volcanic trend (lineament), since both features have the same orientation, and are on line with each other (fig. 15).

The initial basaltic volcanism was apparently followed by erosion during which most of the Fence Lake Formation and part of the "Basalt of Tejana Mesa" was removed in the vicinity of Mesa Tinaja. In this area, there was a second(?) period of volcanism during which basalts (QTob) were extruded from multiple(?) vents around the paleohill of Mesa Tinaja. The northeastward trend of a dike associated with one of these vents, and their proximity to a vent for the "Basalt of Tejana Mesa" (located on the northern portion of Mesa Tinaja), suggests that the "QTob" basalts may represent a reactivation of volcanism along the same master fissure, which produced the "Basalt of Tejana Mesa".

The second(?) period of volcanism was followed by major incision along a northwestward flowing stream, which cut deeply into the area between Tejana Mesa and Mesa Tinaja. All of the Fence Lake Formation, the Baca Formation, and part of the Mesaverde Group were cut through, near the axis of this paleovalley between the mesas. After valley cutting, the channel area was backfilled by the Bidahochi(?) Formation (Pliocene?-Pleistocene?). A third episode of basalt (QTyb) volcanism occurred during the initial stages of Bidahochi(?) deposition. A local source (feeder dike) for the QTyb flow is not apparent, but may be buried under younger fill in the paleovalley. The Bidahochi(?) Formation of the TM-HD area consists mostly of sand-sized rhyolitic fragments reworked from the Fence Lake Formation, sand-sized basaltic fragments from both local flows and reworked from the Fence Lake Formation, and quartz grains reworked from the Baca Formation. The Bidahochi(?) Formation was the last major stratigraphic unit to be deposited in the TM-HD area. Sedimentation was interrupted at least twice as evidenced by the presence of at least two pedocalcic soil horizons.

Normal faulting in the TM-HD area began in association with the extrusion of the "Basalt of Tejana Mesa" along the vent zone on the southeast flank of Tejana Mesa. The majority of faulting, however, is believed to have occurred after extrusion of these basalts (and possibly even after deposition of the Bidahochi(?) Formation). A through-going fault zone that is closely associated with the basalt dikes and vents of earlier flows is termed the "Tejana Mesa fault zone". The master fault (approximately 250 feet of straigraphic throw) of this zone terminates on a monoclinal flexure of the "Basalt of Tejana Mesa" and older units in the vicinity of Mesa Tinaja. Post-Bidahochi(?) tensional deformation is indicated by a tilt of up to 45 degrees of the northwestern outcrop margin of the Bidahochi(?) Formation, toward the Tejana Mesa fault zone, which may reflect subsidence (graben formation) along the fault zone.

CONCLUSIONS

One of the most important results of this study has been the identification and description of a post-Mesaverde, pre-Baca oxidation zone within the TM-HD area. This zone is stratigraphically situated within the top portion of the Mesaverde Group (Late Cretaceous), immediately below the Baca Formation (Eocene). The oxidation zone is interpreted to be part of a lateritic weathering profile and is probably a continuation of a previously described lateritic paleosol in the Datil Mountains-Pietown area (Chamberlin, 1981).

The epigenetic nature of the oxidation zone, is demonstrated by the lower redox boundary of the zone which occasionally cuts bedding at a high angle in the form of "C"-shaped alteration fronts reminiscent of Wyoming-type uranium roll fronts. The great lateral extent of the oxidation zone, which has been observed in the Bear Mountains 70 miles east of the TM-HD area, strongly suggests the oxidation was produced by widespread pedogenesis, rather than by deep ground water alteration after deposition of the Baca Formation. Evidence of the tropical (lateritic) nature of the pedogenesis is provided by the great vertical thickness of the weathering profile (up to 160 feet in the TM-HD area) and by the presence of hematite/limonite pebbles in the basal conglomerate of the Baca Formation, which were probably derived from erosion of an iron cap at the top of the paleosol. Independent confirmation of tropical climatic conditions prior to deposition of the Baca Formation is provided by subtropical to warm temperate pollens and spores, of Late Cretaceous age, identified in the paleosol, and by Paleocene tropical flora found in the Vermejo and Raton Formations of northern New Mexico.

Recognition of the pre-Baca paleosol is important in the understanding of the uranium geology of the Cretaceous and Tertiary rocks of west-central New Mexico, since numerous uranium occurrences and anomalies in this region are spatially associated with the base of the paleosol. Several small uranium deposits, discovered by Gulf Minerals in the "Red Basin" area of the Datil Mountains, were apparently formed by pedogenic and ground water processes in this ancient weathering profile (Chamberlin, 1981). Presumably, acidic vadose water, which was produced by the surface decay of vegetal matter, percolated downward and leached slightly uraniferous (carbonaceous) shales of the Mesaverde Group. The uranium was then redeposited in a more concentrated form at redox boundaries between actively flowing and relatively stagnant ground waters. The uranium mineralization of the TM-HD area is also associated with the base of the pre-Baca paleosol and is therefore also interpreted to have been the result of tropical pedogenesis.

The pre-Baca paleosol is interpreted to be the primary zone of uranium potential in the TM-HD area for two reasons: 1) the tropical pedogenesis, inferred to have produced the oxidation zone (paleosol), provides a viable mechanism for the formation of tabular and roll front ore deposits (Chamberlin, 1981), and 2) there are a number of known uranium occurrences (seven radiometric anomalies and one small deposit) associated with the redox boundary at the base of the oxidation zone.

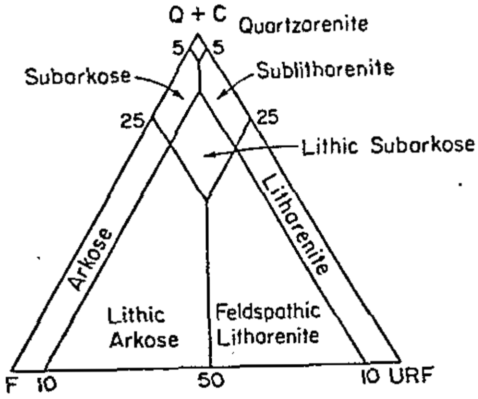
The sandstones of the Baca Formation are another potential host for uranium deposits. Uranium for such possible deposits could have been provided by erosion of the lateritic soil from uplifts and basin margins that flushed uranium rich waters into the Baca Basin (Chamberlin, 1981).

Appendix

Appendix A: Teminology Used for Lithologic and Petrographic Descriptions

Rock Classification

The classification of arenaceous sandstones presented by McBride (1963) was used for thin-section descriptions of the Mesaverde Group, the Baca Formation, the Fence Lake Formation, and the Bidahochi(?) Formation. Constituent volumes were estimated by both visual approximations and point counts of 100.



McBride, 1963

Rock Color

Rock colors were described with the use of the Geological Society of America, rock-color chart (Goddard and others, 1979) whenever possible. Some of the deep and brilliant shades of red of the Baca Formation and the post-Mesaverde, pre-Baca altered zone did not appear on the color chart. All color terms in the text, taken from the chart, are followed by the appropriate number-letter code.

Grain Size

The grain-size classification system of Wentworth (1922) was used on all grain-size estimates.

Diameter (in millimeters)	Size term
	boulder
256	
	cobble
64	
	pebble
4	
	granule
2	
	very coarse sand
1	
	coarse sand
1/2	
	medium sand
1/4	
	fine sand
1/16	
	very fine sand
1/256	

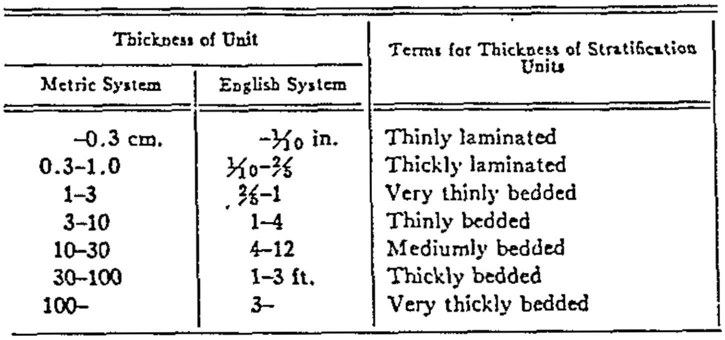
Sorting

Terminology for the degree of sorting of clastic grains was taken from Folk (1968).

Diameter ratio	Verbal scale
1.0	
	very well sorted
1.6	
	well sorted
2.0	
	moderately sorted
4.0	
	poorly sorted
16.0	
	very poorly sorted

Bedding

The bedding terminology and size classification of Ingram (1954) was used in this study.



Thickness of Unit		Terms for Thickness of Stratification Units
Metric System	English System	
-0.3 cm.	-1/10 in.	Thinly laminated
0.3-1.0	1/10-2/5	Thickly laminated
1-3	2/5-1	Very thinly bedded
3-10	1-4	Thinly bedded
10-30	4-12	Mediumly bedded
30-100	1-3 ft.	Thickly bedded
100-	3-	Very thickly bedded

Cross-Stratification Size

Terminology for the magnitude of cross-stratification is based upon the length of individual sets. Size terms defined by McKee and Weir (963) were used in this study.

Magnitude of cross-strata	Length of cross-strata
small scale	<1 foot
medium scale	1-20 foot
large scale	>20 foot

Appendix B: Clay Mineral Data and Methods of Analysis

Sample Preparation:

1.) Samples were crushed to a size of less than 1/16 inch and 45 grams of each sample was disaggregated in 250 ml of distilled water for 2 hours.

2.) The mixture was allowed to stand for 2 hours after disaggregation.

3.) If the clays flocculated, the sample was boiled in 650 ml of an EDTA solution for 4 hours to remove the flocculating agents such as gypsum, dolomite, and CaC03 (see Bodine and Fernalld, 1973). After boiling, the EDTA was poured off and the sample was washed by mixing the clay with distilled water, centrifuging it, and then pouring off the water. This washing procedure was repeated 3 times. Steps 1 and 2 were then repeated.

4.) Suspension from the upper 2 cm of the solution, which represents the less than 2 micron fraction, was pipetted onto 3 glass slides for each sample.

Clay Mineral Analysis:

For each set of sample slides, 4 X-ray determinations were made to identify the clay minerals (see Carroll, 1970) and to provide data for semi-quantitive analysis.

1.) The first slide was X-rayed to determine (001) basal spacings.

2.) A second slide was exposed to ethylene glycol in a dessicator for 24 hours and then X-rayed to identify the expandable clays (smectite).

3.) The third slide was heated at 350 C for 2 hours and then X-rayed to detect the collapse of smectite.

4.) The same slide was then heated at 550 C for 2 hours, to degrade the kaolinite, and then X-rayed to detect chlorite. When present, kaolinite masks the presence of chlorite on diffractograms.

Semi-Quantitive Analysis:

The following method of semi-quantitive analysis was supplied by Dr. George Austin of the New Mexico Bureau of Mines and Mineral Resources (written communication, 1982). The equations listed below provide abundances of the major clay mineral groups to parts per 10. The variables for the equations are the peak heights, above background, of the following clay species:

K = Kaolinite (001) reflection of the untreated slide.

Igl = Illite (001) reflection of the glycolated slide.

Sgl = Smectite (001) reflection of the glycolated slide.

S350 = Smectite (001) reflection of the slide heated to 350 C. Note that during sample analysis, these slides were X-rayed within 2 minutes from their removal from the oven in order to obtain their maximum peak intensities (see Austin and Leininger, 1976).

T = S350 + K

Smectite(ppt) = (Sgl/4)/T

Kaolinite(ppt) = K/T

Illite(ppt) = Igl/T

Mixed-layer illite-smectite(ppt) = (S350-(Sgl/4)-Igl)/T

There were essentially no mixed layer clays in any of the samples since illite was either absent or was found in only minor or trace amounts in the samples. Results of the clay analysis are presented in Table 5 along with the sample locations.

Table 5. Clay mineralogy of all mudstone/claystone samples along with sample locations.

Sample No.	Unit Sampled	Location	Clay Mineralogy (parts per ten) Smectite	Kaolinite	Illite	Color
TM 241	Baca	SW1/4SE1/4SW1/4 sec. 21, T.4N., R.15W.	9	1	trace	dark reddish maroon
TM 195	Ox. Zone (pre-Baca)	NE1/4SE1/4 sec. 16, T.3N., R.16W.	2	7	1	light gray
TM 196	"	" "	5	5	trace	pale reddish purple
TM 201	"	NW1/4SW1/4 sec. 15, T.3N., R.16W.	3	7	trace	grayish orange
TM 202	"	" "	10	trace	trace	pale reddish purple
TM 203	"	" "	4	5	1	grayish orange
TM 204	"	" "	4	5	1	grayish orange
TM 194	Mesaverde	NE1/4SE1/4 sec. 16, T.3N., R.16W.	10	trace	trace	medium gray
TM 211	"	NE1/4SE1/4NE1/4 sec. 15, T.3N., R.16W.	10	trace	trace	yellowish gray
TM 240	"	NW1/4SW1/4NE1/4 sec. 21, T.3N., R.16W.	5	4	1	yellowish gray
TM 243	"	NE1/4NW1/4NW1/4 sec. 29, T.4N., R.15W.	8	2	trace	yellowish gray
TM 244	"	" "	5	5	trace	dusky yellow
	Samples from the Datil Mountains-Pietown area (collected by R. M. Chamberlin).					
RB 11	Ox. Zone	NW1/4NE1/4SE1/4 sec. 19, T.2N., R.10W.	6	3	1	light purplish gray
RF 20	"	SE1/4SE1/4 sec. 27, T.2N., R.10W.	5	5	0	light purplish gray

Appendix C: Paleocurrent Data and Methods of Analysis

Paleocurrent data were derived from measurements taken on trough cross-stratification, planar cross-stratification, and parting lineations. Unidirectional current data were provided by measuring the azimuth direction of maximum foreset dip of planar cross-stratification and the azimuth direction of trough axis plunge. Dott (1973) discusses the use of trough axes as current indicators and demonstrates that the direction of plunge of a trough axis is a far superior paleocurrent measurement than that of the orientation of cross-stratification within a trough.

Bidirectional current data were provided by measuring the strike of parting lineations. The genesis and use of this current indicator is described by Stokes (1947) and McBride and Yeakel (1963). According to these authors, the lineations are produced by a preferred orientation of the long axes of detrital grains. This orientation is the result of a streaming effect of sand particles parallel to current direction. In the field, these lineations appear as subparallel shallow linear grooves and low-relief ridges (generaly less than 1 mm) on bedding surfaces. In areas where parting lineations are not observed on outcrop surfaces, they can sometimes be uncovered by splitting strata parallel to bedding.

Parting lineations were the only current indicators utilized in the Baca Formation. This was due to both the scarcity of planar cross-stratification in the Baca Formation and the very poor exposure of trough axes. A current direction was assigned to the parting lineation strike data from both the Mesaverde Group and the Baca Formation by observing the direction of foreset dip of numerous planar and/or trough cross-stratified sets in the vicinity of the parting lineations measured. A total of eight paleocurrent directions were obtained by this method for the Baca Formation. Seven of these were measured in the vicinity of Mariano Mesa due the excellent exposures of the Baca Formation at this location.

Paleocurrent measurements from the Mesaverde Group were made on all three of the previously discussed current indicators. High and Picard (1974) have shown that trough axes provide a more reliable and precise paleocurrent directon than planar cross-stratification. Only a few measurements of trough axes are needed to determine true channel direction. Therefore, because of these differences in reliability, data from the three current indicators were plotted on separate rose diagrams. Note that in Figure 7 only three trough cross-stratification measurements were taken. These were large-scale troughs that were located close to one another (see Table 6) and stratigraphically were within 25 feet of one another. Although only three measurements were taken, these data are considered to be

Table 6. Paleocurrent data and measurement locations.

Current Indicator	Current Azimuth	Formation	Measurement Location
1 PLN	180	Baca	NW1/4SW1/4 sec. 21, T.3N., R.15W.
2 "	70	"	SW1/4SW1/4NE1/4 " "
3 "	100	"	" "
4 "	65	"	NE1/4 " "
5 "	115	"	" "
6 "	165	"	W1/2SW1/4 sec. 15, " "
7 "	80	"	SW1/4NE1/4 " "
8 "	65	"	SE1/4SW1/4 sec. 21, T.4N., R.a5W.
1 TCS	340	Mesaverde	SE1/4NE1/4SE1/4 sec. 16, T.3N., R.16W.
2 "	12	"	" "
3 "	20	"	NW1/4SW1/4 sec. 15, " "
1 PLN	65	Mesaverde	NE1/4NW1/4SE1/4 sec. 31, T.3N., R.16W.
2 "	97	"	NW1/4SE1/4 sec. 29, T.4N., R.15W.
3 "	63	"	NE1/4SE1/4NW1/4 " "
4 "	3	"	NW1/4NW1/4 sec. 17, T.3N., R.15W.
5 "	8	"	" "
6 "	21	"	NW1/4SW1/4 sec. 11, " "
1 PCS	107	Mesaverde	SW1/4SE1/4SE1/4 sec. 32, T.4N., R.15W.
2 "	178	"	" "
3 "	110	"	" "
4 "	155	"	" "
5 "	71	"	SW1/4SW1/4NE1/4 sec. 36, T.4N., R.16W.
6 "	140	"	" "
7	6	"	" "
8 "	96	"	" "
9 "	188	"	" "
10 "	59	"	" "
11 "	139	"	" "
12 "	57	"	NW1/4NW1/4 sec. 17, T.3N., R.15W.
13 "	42	"	" "
14 "	103	"	" "
15 "	90	"	" "
16 "	74	"	" "
17 "	31	"	" "
18 "	57	"	" "
19 "	53	"	N1/2SW1/4 sec. 24, T.3N., R.16W.
20	105	"	" "

(Continued on following page)

Abbreviations:

PLN=parting lineation
TCS=trough cross-stratification
PCS=planar cross-stratification

21	PCS	65	Mesaverde	N1/2SW1/4 sec. 24, T.3N.,	R.16W.
22	"	35	"	"	"
23	"	155	"	W1/2E1/2SE1/4 sec. 29, "	"
24	"	23	"	"	"
25	"	155	"	"	"
26	"	31	"	"	"
27	"	96	"	"	"
28	"	329	"	NW1/4SE1/4SW1/4 sec, 21, "	"
29	"	337	"	"	"
30	"	40	"	"	"
31	"	2	"	"	"
32	"	93	"	"	"
33	"	29	"	"	"
34	"	26	"	"	"
35	"	299	"	N1/2SE1/4NE1/4 sec. 16, "	"
36	"	307	"	"	"
37	"	330	"	"	"
38		335	"	"	"
39	"	319	"	"	"
40	"	48	"	"	"
41	"	358	"	"	"
42	"	341	"	"	"
43	"	272	"	"	"
44	"	38	"	"	"
45	"	273	"	NW1/4SW1/4NE1/4 "	"
46	"	242	"	"	"
47	"	250	"	"	"
48	"	336	"	E1/2E1/2SW1/4 sec. 22 "	"
49	"	304	"	"	"
50	"	340	"	"	"
51	"	355	"	"	"
52	"	1	"	"	"
53	"	162	"	SE1/4SW1/4SW1/4 sec. 12 "	"
54	"	100	"	"	"
55	"	93	"	"	"
56	"	189	"	"	"
57	"	143	"	"	"
58	"	219	"	E1/2SW1/4 "	"
59	"	213	"	"	"
60	"	263	"	"	"
61	"	35	"	SW1/4NW1/4SW1/4 "	"
62	"	79	"	"	"
63	"	95	"	"	"
64	"	26	"	"	"
65	"	36	"	"	"
66	"	95	"	NE1/4NE1/4NW1/4 sec. 15 "	"
67	"	80	"	"	"
68	"	55	"	"	"
69	"	180	"	"	"
70	"	140	"	"	"
71	"	102	"	"	"
72	"	85	"	NW1/4NE1/4NW1/4 sec. 28 "	"
73	"	92	"	"	"
74	"	49	"	NW1/4SW1/4SE1/4 sec. 20 "	"
75	"	47	"	"	"
76	"	80	"	"	"
77	"	274	"	N1/2SE1/4NE1/4 sec. 16 "	"

significant due to the superior reliability and precision of trough axis data. The high degree of scatter of the planar cross-stratification data (see fig. 7) is typical of this particular current indicator. However, the relatively large number of measurements collected from this indicator compensates somewhat for the scatter and provides useful paleocurrent data (High and Picard, 1974).

All of the paleocurrent measurements used to construct the rose diagrams of Figures 7 and 10 are listed in Table 6 along with measurement locations. The data are presented as azimuth current directions that have been corrected for tectonic dip when necessary. The average current direction for each rose diagram (ie. vector mean) was calculated by a vector summation program supplied by Dr. D. B. Johnson of the New Mexico Institute of Mining and Technology. Along with each vector mean a vector strength value was calculated by the program. Vector strength varies from 0.0 to 1.0. A value of 0.7, for example, would indicated that 70% of the sum of the vectors contributed to the vector mean.

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This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Richard M. Chamberlin
Adviser

Clay T. Smith

David B. Johnson

John R. MacMillan

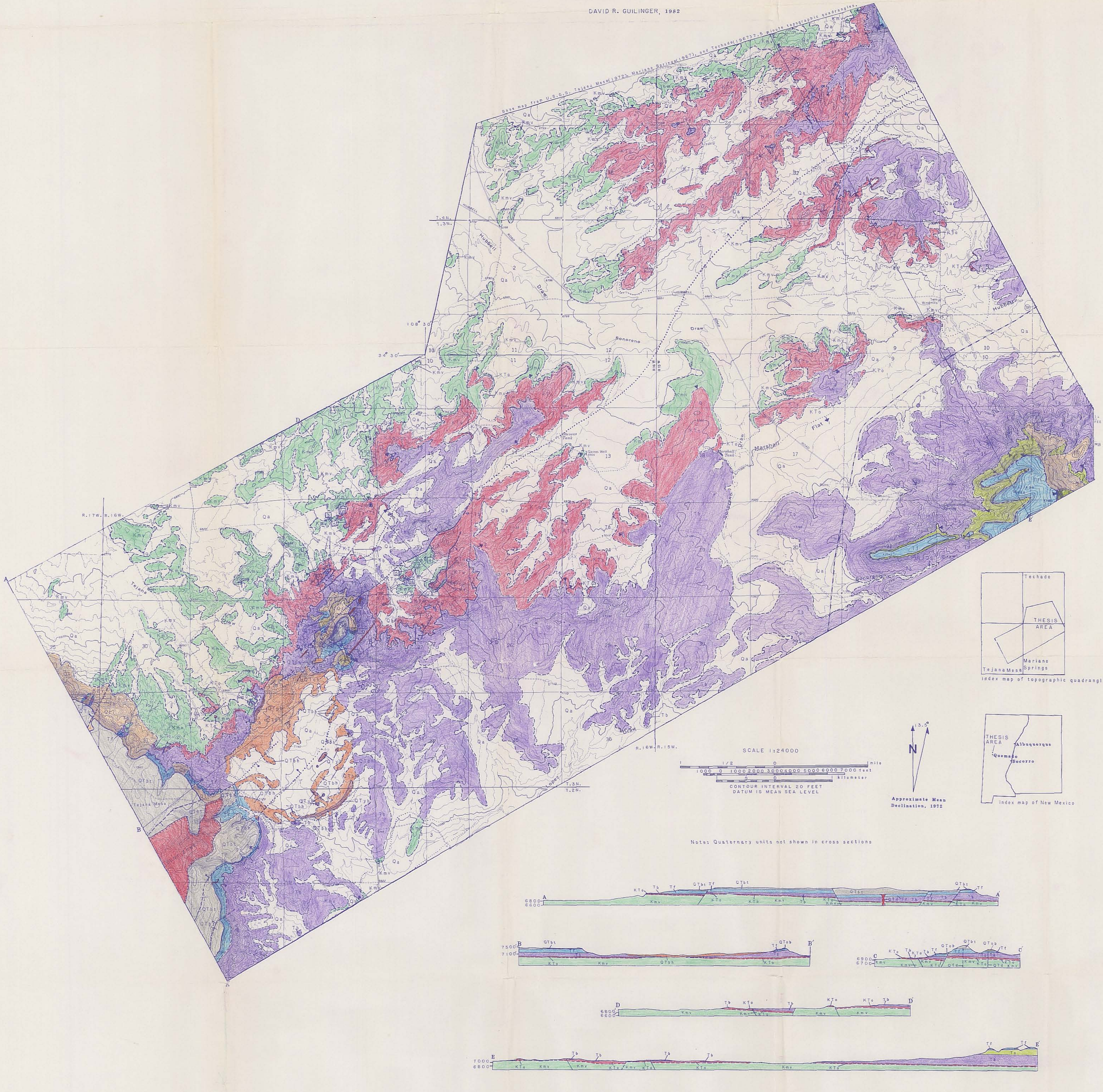
Sept. 29, 1982
Date

GEOLOGIC MAP AND SECTIONS OF THE TEJANA MESA-HUBBELL DRAW AREA

CATRON COUNTY, NEW MEXICO

by

DAVID R. GUILINGER, 1982



Note: Quaternary units not shown in cross sections

EXPLANATION

(See figure 3 for description of map units)

QUATERNARY

- Qa — Alluvium
- Qt — Talus
- Ql — Landslide Block

unconformity

- QTbh / QTyb — QTbh: Bidahochi(?) Formation; QTyb: young basalt flows

unconformity

- QTob — Old basalt flows (relation to QTbt uncertain)

unconformity

PLIOCENE

- QTbt — Basalts of Tejana Mesa; Zone of red scoria in vent zone
- QTd — QTd: Basalt di

MIOCENE

- Tf — Fence Lake Formation

unconformity

OLIGOCENE

- Ts — Spears Formation

EOCENE

- Tb — Baca Formation

unconformity

CRETACEOUS

- KTo — Post-Mesaverde, pre-Baca oxidation zone
- Kmv — Mesaverde Group

Contact
Dashed where approximately located dotted where inferred under cover triangle indicates position of well exposed contact

Contact showing dip, solid arrow indicates dip derived from a three point calculation on contact

High-angle fault
Ball on downthrown side, shows bearing and plunge of slickensides, dashed where approximately located, dotted where inferred under cover

Monocline
Dashed where inferred, dotted where inferred under cover

Strike and dip of bedding

Apparent dip of bedding

Radiometric anomaly
number in box X 100 = cps gamma radiation

Chemical alteration front cutting across bedding at base of KTo, symbol points toward reduced rock and opens toward oxidized rock

Volcanic vent

Volcanic neck

Measured section of post-Mesaverde, pre-Baca oxidation zone (shows offsets in section traverse)

Fossil locality

Uranium occurence
(V) Varnum deposit
(M) Mangum prospect
(exact location uncertain)