# GEOLOGY AND COAL RESOURCES OF THE CUB MOUNTAIN AREA, SIERRA BLANCA COAL FIELD, NEW MEXICO

by

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# ABSTRACT

In the Sierra Blanca Basin, coal occurs within the Upper Cretaceous Mesaverde Group. In an effort to gain knowledge of coal resources, this study examined a portion of the Sierra Blanca coal field near Carrizozo, New Mexico.

The Mesaverde Group contains three members in the Carrizozo area. The Lower Sandstone Unit is composed of more than 120 feet of clean quartz sandstone deposited along a regressive marine shoreline. Conformably overlying this is the Transitional Unit consisting of 95 feet of sandstone, siltstone and claystone. These were deposited at the continent-ocean interface as lagoonal, tidal flat and deltaic sediments. Although data are presently inconclusive, these two units may correlate with Gallup Sandstone.

Conformably overlying the Transitional Unit are coastal plain sediments of the Continental Unit. The lower 210 feet consist predominantly of floodplain claystones and siltstones with some intercalated fluvial sandstones. The upper 260 feet consist of fluvial sandstones with lesser volumes of floodplain claystones, siltstones and coal. Although data are presently inconclusive, the Continental Unit may be equivalent to parts of the Crevasse Canyon Formation. Conformably overlying the Continental Unit are braided stream deposits belonging to the Upper Cretaceous(?) to Tertiary Cub Mountain Formation.

Four horizons in the middle to upper Continental Unit contain coal. Coal beds are in most places thin, discontinuous and shaly. One horizon on Cub Mountain contains a seam ranging from 3.5 to 4.0 feet thick with good continuity for about 3500 feet along strike. Demonstrated resources for this seam are approximately 3.5 million tons. Under exceptional marketing conditions, this seam may have potential for small-scale production. Throughout the remainder of the study area, steep dips, thin, discontinuous seams and an unfavorable paleoenvironment for coal formation indicate little to no potential for the presence of minable coal deposits.

# INTRODUCTION

In the vicinity of Carrizozo, New Mexico, along a northerly strip from Three Rivers to White Oaks (fig. 1.1), coal occurs within the Upper Cretaceous Mesaverde Group. The occurrence constitutes the western portion of the Sierra Blanca coal field (fig. 1.2). For many years, the Sierra Blanca field has been considered a potentially promising source of coal. Read and others (1950) estimated a possible coal resource of 1.6 billion tons. However, little is known of the detailed geology and coal potential and an accurate resource assessment is not currently available. This is especially true of the western portion of the field. Though the area has been the site of some confidential exploration programs, including drilling, virtually nothing is reported in the literature on the Cretaceous rocks or coal of the western portion.

With this in mind, this study examined the geology and coal resources of part of the western Sierra Blanca field. The project had three goals:

1. to study the geology of the area with special emphasis on the coal-bearing Cretaceous rocks,
2. to assess the coal resources of the area, and
3. to provide basic information for other coal-related studies in adjoining areas.

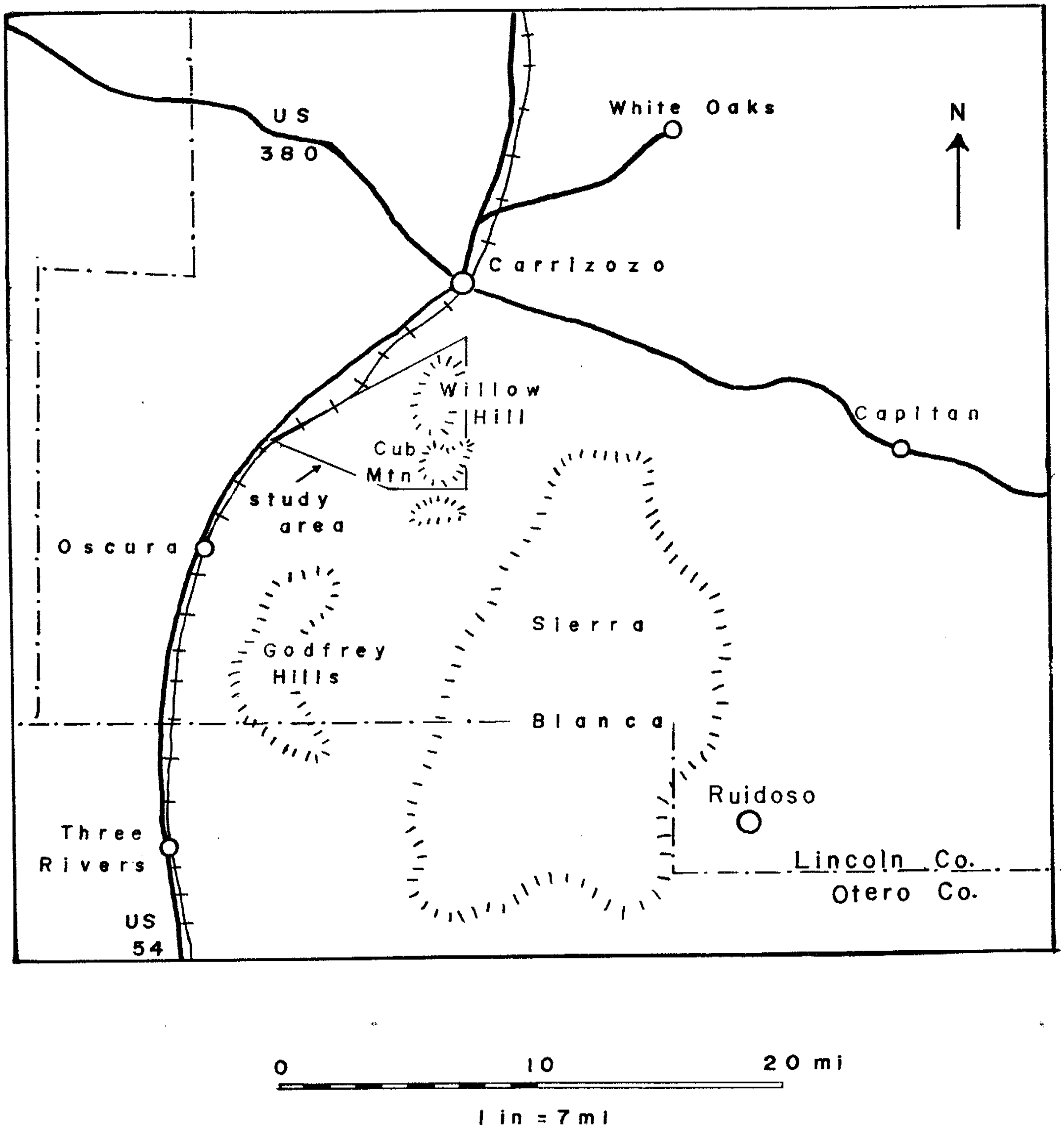


Fig. 1.1 - Index map of study area
(base map adapted from Allen & Kottlowski, 1981, Geologic Map)

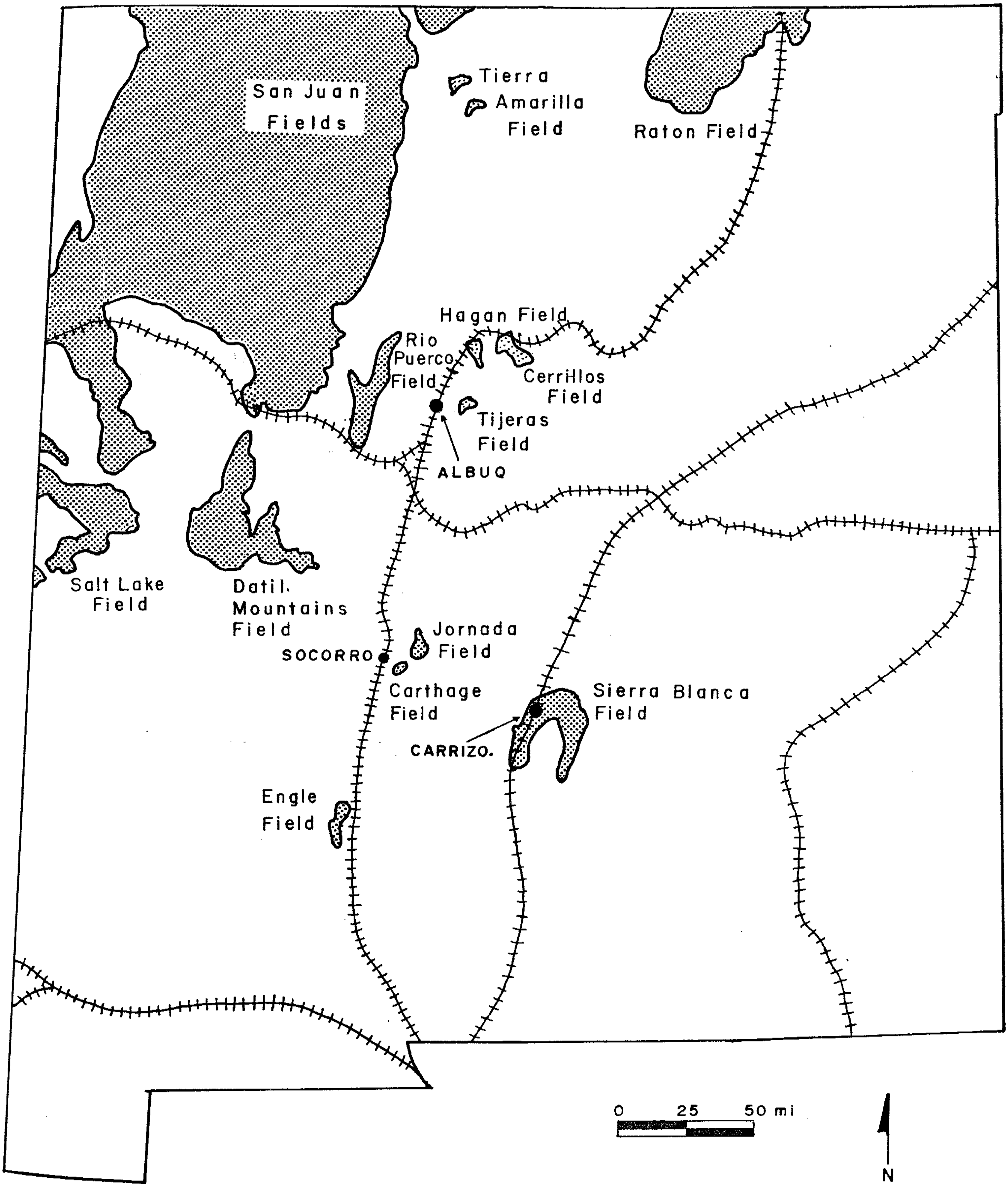


Fig. I.2 Coal fields in New Mexico
(source: N. Mex. Bureau Mines & Min. Resources)

## Design of Project

The project was designed to be carried out in two stages. The first was to examine the entire western Sierra Blanca field to locate a suitable area for more detailed study. The initial region examined ran from Three Rivers in the south to White Oaks in the north (fig. 1.1). After a brief reconnaissance, a study site at Cub Mountain was selected because of its central location, good coal exposure and resource potential.

The second phase of the project was the actual geologic and coal resource study. Geologic studies were made of stratigraphy, depositional environments and structure of the Mesaverde Group placing special emphasis on the coal-bearing sections. Resource studies were directed at the amount, character and distribution of the coal.

## Method of Study

Geologic mapping was carried out over an area of approximately 20 square miles on a scale of 1:24,000 in parts of the Cub Mountain and Church Mountain topographic quadrangles. Because of poor resolution, aerial photographs proved inadequate for mapping and could only be used in limited aspects of the final map compilation. Early in the field work, 17 stratigraphic sections were measured using Jacob Staff and Brunton compass. Fossils were collected during mapping and section measuring to aid in determining stratigraphy and depositional environments. Petrographic descriptions were obtained from hand sample analysis; five thin sections were analyzed from typical locations in the Mesaverde Group and Cub Mountain Formation. Rock classification follows Pettijohn (1975); classification of sedimentary structures follows McKee and Weir (1963), except when referring to the angle of cross-stratification. McKee and Weir (1963) define only low and high angle cross-strata; this study defines low (<8 degrees), medium (8 to 18 degrees) and high (>18 degrees) angle cross-strata.

The coal resource evaluation was carried out by examination of outcrops, prospect trenches and subsurface drilling data. Log descriptions, gamma logs and some electric logs were obtained for 15 drillholes placed throughout the study area. Although the drill data allows some interpretation, the principle conclusions for the coal resource evaluation were deduced from surface studies.

## Previous Work

Little work has been done on the coal resources of the Sierra Blanca field. Wegemann (1912) published the results of a reconnaissance survey done by the U.S. Geological Survey. An unpublished report by Melhase (1927) contained some generalized information on portions of the field, including the Cub Mountain area. Bodine (1956) published a report concerning geology and coal resources near Capitan. Although Capitan is about 25 miles from Cub Mountain, the report contained pertinent information, especially on stratigraphy. A study by Weber (1964) provided considerable information on the general geology of the study area.

## Location and Access

The Sierra Blanca coal field is located in south-central New Mexico in Lincoln and Otero counties (fig 1.2). This project examined an area south and southeast of Carrizozo in the vicinity of Cub Mountain (fig. 1.1).

Carrizozo is accessible via U.S. 380 from the east and west and U.S. 54 from the north and south. Dirt roads provide access to most of the study area. Use of these roads is dependent on land ownership and the condition of the road. Most often, a truck or off-road vehicle is required, especially during rainy seasons.

Major airports are located at Alamogordo, 50 miles south and Roswell, 90 miles east. In addition, small airports are located at Carrizozo and Ruidoso. A branch of the Southern Pacific railroad runs through the area, roughly parallel to U.S. 54.

## Geographic Setting

The area has a mild, arid to semi-arid, continental climate. It is characterized by light precipitation, abundant sunshine and low relative humidity. Large annual and diurnal temperature fluctuations are typical. Precipitation, mostly rain, occurs primarily during late summer and early winter. The rest of the year is normally very dry. Temperature and precipitation data from nearby cities are given in table 1.1.

Altitudes in the general vicinity range from about 5000 feet in the Tularosa Basin to 12,003 feet at Sierra Blanca Peak. In the study area, elevations range from 5200 feet to a maximum of 7877 feet at Cub Mountain. Topography is gentle in the western part of the study area; rolling hills and steep terrain characterize the eastern portions.

Vegetation in the area is sparse and falls in the Desert Grasslands and Pinon-Juniper zones (Martin, 1964). The desert grasslands zone is characterized by cresote bush and various species of yucca, mesquite, cactus and grass. Above 6000 feet is the Pinon-Juniper zone. This is characterized by Pinon, Juniper and scrub oak trees, yucca, cactus and many varieties of grass.

The area is lightly populated. Lincoln County has a 1980 population of 11,000. Carrizozo, the largest town in the county, has a population of 1500. The nearest cities of any size are Alamogordo and Roswell with populations of 24,000 and 39,650 respectively.

There is no major industry in the Carrizozo area. The main occupations are ranching and related disciplines.

Employment opportunities are minimal; thus, there exists an available pool of unskilled to semi-skilled labor. Since mining has been practiced in the area from time to time, there are a small number of workers knowledgeable in the mining occupation.

## Acknowledgments

The study presented herein could not have been done without considerable aid from a number of people and organizations. In particular, appreciation is extended to members of the thesis advisory committee: Drs. Clay Smith, Frank Kottlowski and John MacMillan. Special thanks are extended to Frank Campbell and Gretchen Roybal for assistance and advice throughout the project. Finally, I would like to express my thanks to Kelly and Bill Stephenson, proprietors of the I-X Ranch, for their hospitality and for allowing access to their land during fieldwork.

A major portion of the funding for this project was provided by the New Mexico Bureau of Mines and Mineral Resources. In addition, grants from Kennecott Minerals Co. and New Mexico Geological Society helped defray the expense of the project.

### TABLE 1.1 - TEMPERATURE & PRECIPITATION DATA

(source: Gales Research Co., 1980)

| ALAMOGORDO | AVG. T ( F) | AVG. PP (In.) |
|---|---|---|
| Jan. | 42.3 | 0.57 |
| Apr. | 60.8 | 0.22 |
| Jul. | 80.4 | 2.23 |
| Oct. | 62.0 | 1.19 |
| Year | 61.2 | 10.62 (total) |
| Low | 42.3 (Jan.) | 0.22 (Apr.) |
| High | 80.4 (Jul.) | 2.23 (Jul.) |

| CARRIZOZO | AVG. T (F) | AVG. PP (In.) |
|---|---|---|
| Jan. | 36.6 | 0.47 |
| Apr. | 55.1 | 0.34 |
| Jul. | 76.1 | 2.39 |
| Oct. | 56.7 | 1.17 |
| Year | 55.8 | 12.69 (total) |
| Low | 36.6 (Jan.) | 0.34 (Apr.) |
| High | 76.1 (Jul.) | 2.60 (Aug.) |

# STRATIGRAPHY

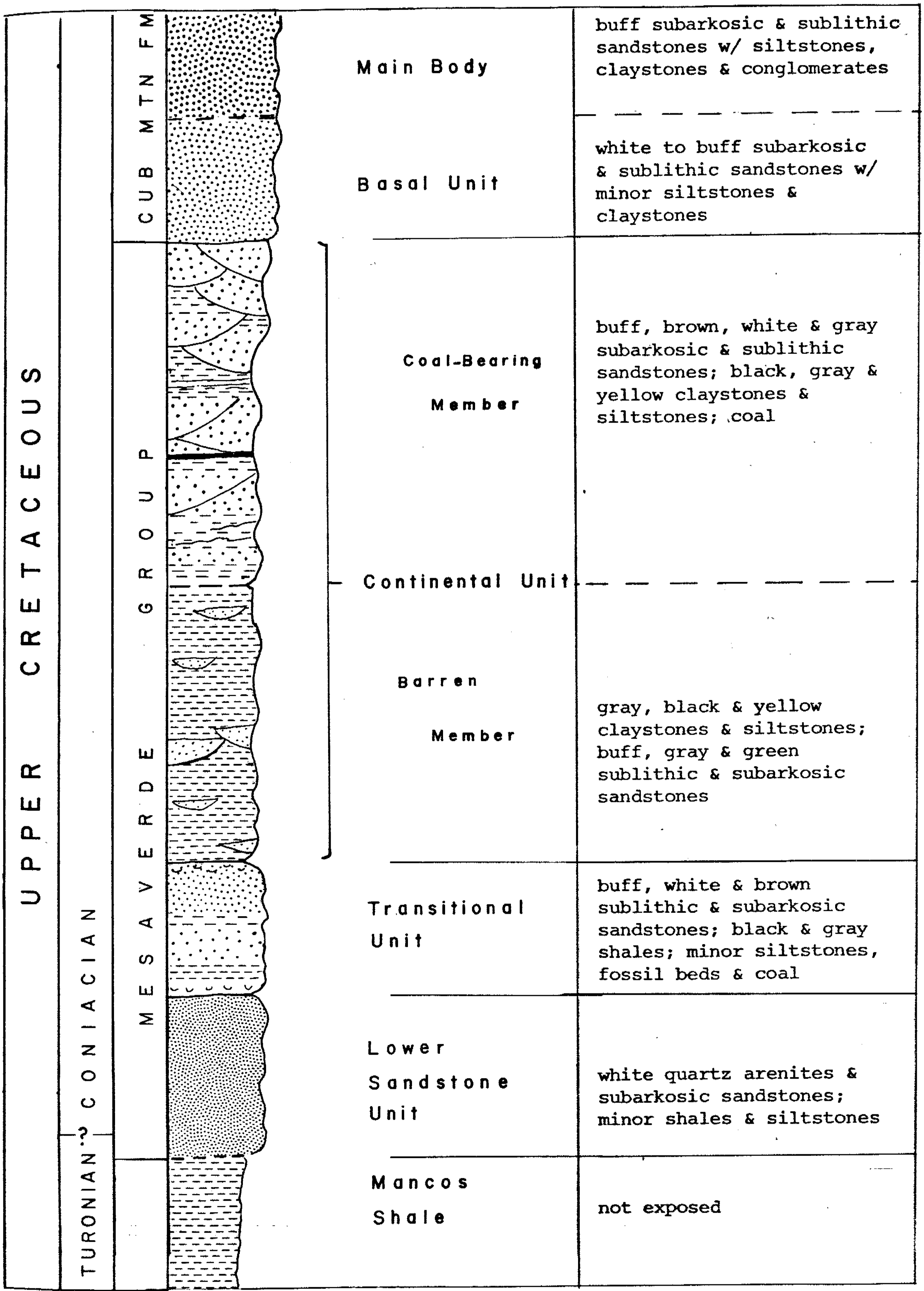
## MESAVERDE GROUP

The Sierra Blanca Basin contains rocks ranging from Precambrian to Quaternary in age. The lowest exposures in the study area are strata of Upper Cretaceous Mesaverde Group. Currently within the Sierra Blanca Basin, there is no formal subdivision of the Mesaverde Group. Bodine (1956) subdivided the Mesaverde near Capitan into three informal members: a lower sandstone, a middle shale and an upper sandstone. In the Cub Mountain area, this study divides the Mesaverde Group into three units: Lower Sandstone Unit, Transitional Unit and Continental Unit (fig. 2.1). In addition, the Continental Unit is informally divided into Barren and Coal-Bearing Members. In comparison, the Lower Sandstone and Transitional Units are basically equivalent to Bodine's Lower Sandstone; the Continental Unit is essentially equivalent to the Middle Shale of Bodine. The major difference between this study and that of Bodine is the formational assignment of the sandstone body above the Continental Unit. Bodine defined this unit as the Upper Sandstone of the Mesaverde Group. In contrast, this study considers the unit part of the Cub Mountain Formation.

### Lower Sandstone Unit

Overlying the Mancos Shale is the Lower Sandstone Unit of the Mesaverde Group. The contact is not exposed in the

Fig. 2.1 — Generalized stratigraphic column



study area; however, a few miles west of the study area, Weber (1964) reported the contact as gradational and interfingering with Mancos Shale. A minimum thickness for the Lower Sandstone Unit was measured as 120 feet.

The Lower Sandstone is composed predominantly of clean quartz sandstone. Some shale, siltstone and fossil beds occur, comprising about 5 percent of the total volume. The lower exposures are thinly bedded, fine to very fine grained subarkosic sandstones with minor shale and siltstone interbeds. Upwards in section, grain size increases slightly and rocks show a higher degree of compositional and textural maturity. Percentage of feldspar, lithics and matrix decrease while degree of sorting increases from moderately to well sorted. Through the middle of the unit, fine to medium grained subarkosic sandstones predominate. These have a small amount of interbedded shale and siltstone and fossiliferous sandy siltstone lenses. The upper portions of the unit are quartz arenites and subarkosic sandstones. The sandstones are medium to fine grained, well rounded, and very well sorted. Grains are predominantly quartz with 5 to 10 percent combined feldspar, rock fragments, heavy minerals and calcite.

Primary sedimentary structures are predominantly horizontal laminae or planar cross-beds with minor trough cross-beds and ripples. Much of the unit is structureless. In the lower portions, horizontal laminae and low angle planar cross-strata predominate. Upwards in section, medium angle cross-strata and structureless beds predominate. Erosional surfaces are much more abundant in the upper strata. At the top of the unit, some high angle (22 degrees or more) cross-beds were noted (fig. 2.2).

Bioturbation is common throughout the unit. No overall trends in type or amount of bioturbation were noted; however, extensive bioturbation is restricted to certain beds. Ophiomorpha were identified in some of the upper beds of the unit. These burrows are generally vertical to sub-vertical and often show truncation by erosion. In addition, Thallassinoides and Chondrites are believed to be present but could not be positively identified.

## Transitional Unit

The Transitional Unit consists of 95 feet of sandstone, claystone and shale with minor siltstone, fossil beds and coal. Individual rock units are laterally discontinuous; strata tend to swell and taper. The contact with the underlying Lower Sandstone Unit is sharp but conformable. The contact is drawn along the bottom of a continuous fossil bed overlying the thick quartz sandstone sequence of the Lower Sandstone Unit (plate 3A). This marks a change from relatively uniform, marginal marine, quartz sandstone to non-uniform, coastal and marginal continental sediments of varied lithologies.

FIG. 2.2 - Eolian cross-beds at top of Lower Sandstone Unit. Line indicates dip of strata.

Sandstones of the Transitional Unit are markedly different from the underlying Lower Sandstone Unit in terms of composition and texture. They are buff colored, sublithic and subarkosic sandstones composed of quartz with abundant feldspar and rock fragments. Chloritized rock fragments and other highly unstable constituents are relatively common. Moderate to large amounts of matrix occur, estimated in the 3 to 8 percent range. Texturally, the sandstones are medium to fine grained, poorly to moderately sorted, with angular to subrounded grains. Primary sedimentary structures are generally trough and low to medium angle planar cross-beds. Erosional surfaces are common. A large percentage of the sandstones are structureless. Distinct burrowing is not common; however, many structureless beds are believed to be the result of intense bioturbation.

Extensive beds of black to gray shale and claystone occur in this sequence. These beds are typically discontinuous; however, some persist for lengths of one to two miles along strike. Many are carbonaceous and some contain minor coal stringers. The Transitional Unit contains numerous siltstones and mudstones, generally lenticular and commonly interbedded with very fine grained sandstone. The mudrocks generally exhibit horizontal laminations, ripples and low angle cross-laminae. Bioturbation is very common and in some areas, little or no primary sedimentary structures remain. Bioturbation consists mainly of small animal burrows; however, some plant rooting is present.

Fossils occur throughout the Transitional Unit but are usually restricted to discrete beds or lenses. Fossils of both marine and brackish water habitats were identified in this unit along with plant fragments and rootlets. Many of the fossils occur as broken, disoriented specimens and are undoubtedly a transport phenomena. Table 2.1 lists specimens collected and their individual characteristics. Of particular interest is Cardium curtum which occurs in the same time zone as Inoceramus deformis and indicates a lower Coniacian age (Cobban and Reeside, 1952; Cobban, pers. comm., June 24, 1983).

## Continental Unit, Barren Member

Attempts to study the Barren Member met numerous difficulties. This unit is exposed on the steep upper flanks of Willow Hill where outcrops are obscured by a thick cover of colluvium and large slump blocks (fig. 2.3). The result is that details of this unit are vague and some questions remain unresolved.

Sediments of the Barren Member differ little from the underlying Transitional Unit. Both are an array of discontinuous sandstones and mudrocks. However, the Barren Member lacks marine characteristics. The contact between

*Table 2.1* - Fossils

| NAME | STRATIGRAPHIC LOCATION | HABITAT | AGE RANGE | REMARKS |
|---|---|---|---|---|
| *Flemingostrea aff. prudentia* | Trans. Unit | brackish water | Cen.-Tur.(5) | Identification and habitat from W. Cobban, U.S.G.S., personal comm. |
| *Crassostrea soleniscus* | Trans. Unit & Lower SS Unit | shallow marine & brackish wat. | unknown | do. |
| *Cymbophora sp.* | Trans. Unit | marine | Cret.(1) | do. |
| *Cyprimeria sp.* | Trans. Unit | marine | Cret.(1) | do. |
| *Cardium curtum* | Trans. Unit | marine, usually nearshore | L. Coniacian(3) | do. |
| *Anomia subquadradus(?)* | Trans. Unit | marine | Jur.-Rec.(1) | do. |
| *Rostellinda dalli* | Trans. Unit | marine | Turonian(2) | do. |
| *Inoceramus sp.* | Trans. Unit | marine | Cret.(1) | do.<br>species tentatively identified as *I.rotendadus* or *I.subquadradus* |
| *Turretella sp.* | Trans. Unit | brackish & marine | --- | |
| *Cardium pauperculum* | Trans. Unit | marine | --- | |

sources of information
(1) Shimer & Shrock, 1944
(2) Sohl, 1967
(3) Cobban & Reeside, 1952
(4) Cobban, personal communication
(5) Kaufmann, 1977

the two is drawn along the top of the uppermost fossil bed in the Transitional Unit. This is a consistent buff sandstone containing the uppermost occurrence of marine fossils. The contact is sharp and conformable.

The Barren Member consists of 210 feet of predominantly claystones and siltstones interbedded with and cut by lenses of sandstone. Claystones and siltstones are black, gray and yellow, generally flat-bedded or structureless and are sometimes carbonaceous. Sandstones range in color from buff to green to brown and are generally fine grained, poorly sorted with angular to subrounded grains. Compositionally, the sandstones are mainly quartz with abundant rock fragments and feldspar. Matrix ranges up to 10 percent. Sandstones are generally structureless to horizontally laminated but show occasional trough and low to medium angle planar cross-strata. In a vertical section this alternating sandstone-claystone sequence repeatedly exhibits an overall fining upwards.

### Continental Unit, Coal-Bearing Member

The Coal-Bearing Member consists of at least 260 feet of sandstone, siltstone, claystone and coal. Sandstone is the predominant lithology, comprising an estimated 60 to 75 percent of the interval. Strata are discontinuous, exhibiting lateral and vertical variations in size and lithology.

The occurrence of coal and the abundance of sandstone

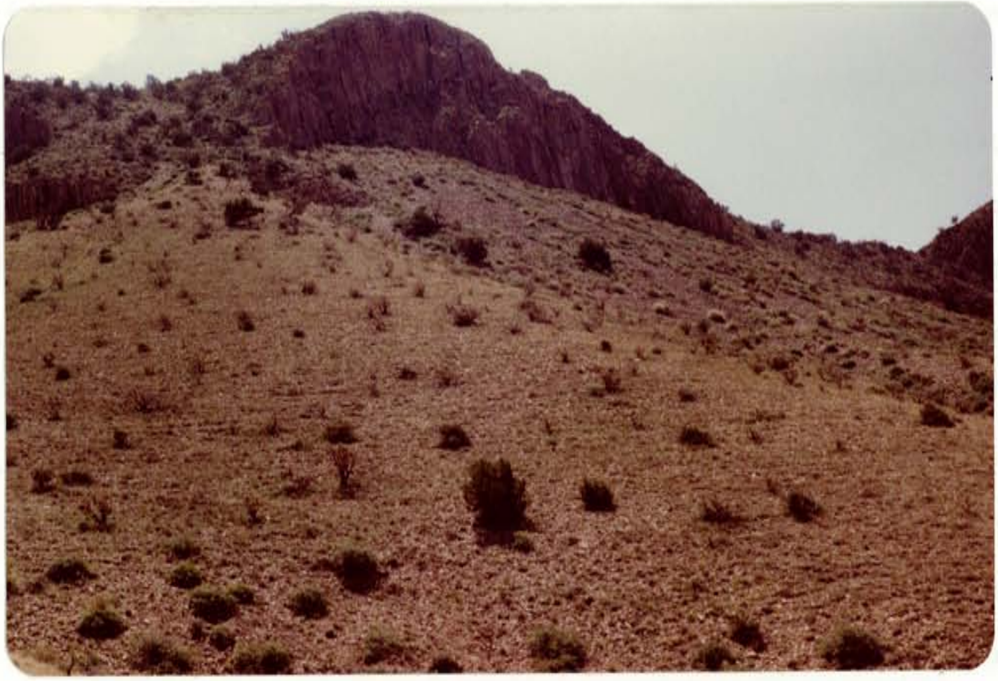


Fig. 2.3 - Colluvium covering Barren Member at Willow Hill. (Cliff at top of picture is about 100 feet thick.)

differentiate this member from the underlying Barren Member. Otherwise, the two members are essentially the same in all respects and the Coal-Bearing Member is more or less a continuation of the Barren Member. The contact is therefore conformable and is arbitrarily defined as the base of the lowest coal seam or a gray-black carbonaceous sandstone. This coal seam is about one foot thick and is fairly continuous across the upper reaches of Willow Hill. Since coals are typically discontinuous, any contact drawn along a coal seam is by its general nature poorly defined. For this reason the contact is somewhat informal. It is intended for the purposes of this study area only, to differentiate between coal-bearing and barren stratigraphic horizons.

The exact thickness of the Coal-Bearing Member cannot be determined in the Cub Mountain area. A fault along Willow Draw (plate 1) offsets the unit in such a manner that the entire section is not exposed. Whereas the basal portion of the unit is exposed at the top of Willow Hill, it cannot be identified on the downthrown portion at Cub Mountain. Therefore, 260 feet represents a minimum thickness. By comparison, this figure gives a total Mesaverde thickness (about 800 feet) in close agreement with other studies in the western Sierra Blanca Basin (Weber, 1964; Haines, 1968; Shmaltz, 1955). Thus, this value is probably close to the true thickness.

Sandstones of the Coal-Bearing Member are composed predominantly of quartz with lesser feldspar and rock fragments. Many contain carbonaceous debris; locally plant fragments and rootlets are noted. Textures range from medium to fine grained, poorly to moderately sorted, with subangular to subrounded grains. Primary sedimentary structures are generally horizontal laminae, low to medium angle planar cross-beds and trough cross-beds. Erosional or scour bases are common. Current ripple marks and fining upward sequences occur sparingly.

Finer sediments are predominantly claystones with some siltstone and mudstone. These are commonly carbonaceous and locally, plant fragments occur. For the most part the mudrocks are featureless except for some horizontal laminae or ripple marks.

Coal is relatively abundant in this unit and occurs in at least four horizons. Three of these are shaly and discontinuous, containing only thin (less than 14 inches) seams. Discontinuity in these seams is due to both erosion and non-deposition. The third horizon (from bottom upward) contains a fairly continuous seam approaching four feet in thickness. With the exception of this seam, coal horizons can be considered claystone sequences with thin, erratic coal beds. A more detailed description of these horizons is given in the discussion of coal resources.

## Correlation with Mesaverde Group to the West

Exposures of Mesaverde Group exist about 65 miles west of the Sierra Blanca Basin at Carthage and along the western edge of the Jornada del Muerto. Baker (1981) noted the occurrence of Gallup Sandstone and Crevasse Canyon Formations in the La Joya area, north of Carthage. At this point there is not enough detailed stratigraphic work in the Sierra Blanca Basin to make formal correlations with rock units to the west. This study, being primarily aimed at coal resources, will not attempt to bring any of the formal nomenclature of the Mesaverde Group into the Sierra Blanca Basin. However, it should be noted that there exists some marked similarities between the Continental Unit and the Crevasse Canyon Formation and between the Lower Sandstone Unit and the marine portions of the Gallup Sandstone (as defined in Molenaar (in prep.) and equivalent to the Main or Upper Gallup of Molenaar (1977)):

1. Lithologies of Gallup Sandstone and the Lower Sandstone Unit are alike. Both are basically clean quartz sandstones, texturally and mineralogically mature.
2. Depositional environments of the Lower Sandstone and Gallup Sandstone are the same. Both are regressive marginal marine shoreline deposits.
3. Lithologies of Crevasse Canyon Formation and the Continental Unit are alike. Both contain an

array of discontinuous, continental sandstones, siltstones, claystones and coal.

4. Depositional environments of the Continental Unit and Crevasse Canyon Formation are similar (neglecting transgressive wedges such as the Dalton Sandstone). Both are coastal plain or flood-plain sediments.
5. The Gallup Sandstone ranges in age from Late Turonian to Early Coniacian (Molenaar, in prep.). Cardium curtum is found throughout the Transitional Unit indicating an early Coniacian age (Cobban and Reeside, 1952). Inoceramus deformis, also of early Coniacian age, is reported by Jensen (in prep.) in the lower sandstones at Capitan. Thus, an early Coniacian or slightly earlier age is indicated for the Lower Sandstone Unit.

The data strongly suggest possible correlations. However, the subject requires more detailed study and formal correlation is left for future workers.

## CUB MOUNTAIN FORMATION

The term Cub Mountain Formation was introduced by Bodine (1956) and later defined by Weber (1964). The sequence consists of arkosic to subarkosic sandstones with interbedded claystones, siltstones and conglomerates deposited in a continental setting. Age limits on the formation are presently uncertain; the unit is generally considered Upper Cretaceous (?) to Eocene (?) in age (Lochman-Balk, 1964).

This study encountered two problems with the previous definition of the Cub Mountain Formation. First, the contact with the Mesaverde Group, as defined, proved very hard to map consistently. The lithologic changes defining the base of the Cub Mountain occur so gradually and transitionally that location of the contact invariably turned out to be an arbitrary decision. The second problem occurred in the definition and formational assignment of the Upper Sandstone Unit of the Mesaverde. Bodine (1956) defined this unit in the Capitan area as a buff to white quartz sandstone with some thin interbeds of shale. He noted extreme variations in thickness. Bodine further stated (p. 8):

> "It is included within the Mesaverde only because of its lithic similarity to the sandstones of the lower member. It is not impossible that this sandstone should be included with the Cub Mountain Formation of Upper Cretaceous or Tertiary age."

Studies of this unit indicate that although it is somewhat similar to the Lower Sandstone Unit, it is much more similar to Cub Mountain Formation. In fact, the lithologies are so similar that it is virtually impossible to draw a contact between the two. Both are subarkosic and sublithic sandstones, with immature textures. By contrast, the Lower Sandstone Unit is a very clean, highly mature quartz sandstone. Depositional environments provide further evidence. Whereas the Lower Sandstone is a regressive marine shoreline deposit, both the Cub Mountain Formation and Bodine's Upper Sandstone Unit are continental braided stream deposits. Table 2.2 gives a comparison of the features of the Cub Mountain Formation, Upper Sandstone Unit and Lower Sandstone Unit.

Based on the transitional contact, lithologies and paleoenvironments, the thick sandstone at the top of the Mesaverde Group is included in the Cub Mountain Formation. For the sake of comparison with other studies, it has been mapped as a separate unit, herein designated the Basal Unit of the Cub Mountain Formation.

## Basal Unit

The Basal Unit is an uniform sandstone with small amounts of interbedded mudrock. The uniform nature and the predominantly sandstone lithology differentiate this unit from the variable lithologies of the underlying Coal-Bearing Member of the Mesaverde Group. The contact between units was drawn along the base of a continuous, clean, white sandstone. The contact is sharp but conformable. Total thickness of the unit is approximately 100 feet.

The lowest portions of the unit are composed of white, subarkosic sandstone. The interval is about 6 feet thick, relatively continuous and uniform, with very little interbedded claystone. Mineralogy is predominantly quartz with lesser feldspar and some rock fragments. Very little matrix is present. It is generally medium grained and well sorted with subrounded grains.

Upwards in section the degree of maturity decreases. The percent quartz decreases with a subsequent increase in feldspar and rock fragments and the introduction of mica. Unstable constituents such as coal fragments and chloritized rock fragments are present. Sorting becomes poorer and angularity increases. The uniform white sandstones at the base grade into buff sandstones with interbedded lenses of claystone and siltstone. Often the sandstones pinch out or grade into finer sediments (fig. 2.4). The result is a cross-sectional profile showing stacked and multilateral channel sandstones encasing small lenses of mudrock.

Primary sedimentary structures are predominantly trough cross-beds. These are quite significant in terms of quantity and size. Medium angle planar cross-beds are common. Horizontal laminae and low angle cross-strata occur to a lesser extent. Erosional surfaces and clay rip-up clasts occur throughout the unit.

Thus, the Basal Unit is characterized by a slow transition from relatively clean, uniform sandstone to more arkosic, angular sandstones with interbedded claystone and

TABLE 2.2(A)- Comparison of Basal Unit to Lower Sandstone Unit

| | Lower Sandstone Unit | Basal Unit |
|---|---|---|
| Composition | Quartz arenite and subarkosic sandstone (fspar + rock frags. ~5-10%). | Sublithic and subarkosic sandstone (fspar + rock frags. ~10-15%). Higher matrix than KmvL. Contains unstable rock frags., coal debris, clay clasts. |
| Texture | Fine-med. grained<br>very well-well sorted<br>well rounded | Med.-fine grained<br>moderately sorted<br>subrounded |
| Primary Sed. Structures | Predominantly planar low-med. angle cross-beds and horizontal laminae. | Predominantly trough cross-beds; some low-med. angle planar cross-beds. |
| Gross Lithology | Continuous sandstone strata; minor interbedded shale and siltstone. | Lenticular sandstone bodies with intercalated lenses of claystone and siltstone. |
| Depositional Environment | Regressive marine shoreline deposit | "Platte Type" braided stream deposit |

Table 2.2(B)-Comparison of Basal Unit of Cub Mountain Fm. (TcmB)* to Main Body of Cub Mountain Fm. (Tcm) (* - Upper Sandstone of Mesaverde Gp. of Bodine, 1956)

| | Basal Cub Mtn.* | Cub Mtn., Main Body |
|---|---|---|
| Composition | Subarkosic and sublithic sandstones; fspar + rk frags ~10-15%; low clay matrix. | Arkosic to subarkosic & sublithic sandstones >15% combined fspar + rk frags; moderate clay matrix |
| Texture | Subrounded, med.-fine grained, moderate sorting | Subangular to angular, coarse to med. grn., mod. to poor sorting |
| Primary Sedimentary Structures | Predominantly trough and med. angle planar cross-beds | Same |
| Gross Lithology | Sandstone with interbedded shale and siltstone | Sandstone with interbedded shale, siltstone and conglomerate |

Table 2.2B - con't.

| | | |
|---|---|---|
| Depositional Environment | Braided stream (Platte Type) | Braided stream |
| Overall Trends | Upward transition toward less mature, more arkosic, more angular sandstone | Same |

Contact of TcmB:

(1) With below (Kmv): sharp and conformable

(2) With above (Tcm): conformable and highly gradational

siltstone. The transition continues upward into the main body of Cub Mountain Formation.

## Cub Mountain Formation, Main Body

The main body of the Cub Mountain Formation has basically the same lithologic character as the Basal Unit. Minor differences occur, such as the presence of conglomerates and redbeds. The main difference is that sandstones show increased angularity, less sorting and slightly coarser grain size. These features follow the trend toward decreased maturity upward.

Sandstones are generally buff colored, contain quartz with abundant feldspar, rock fragments and some mica. They are medium to coarse grained and moderately sorted with subangular to angular grains. Trough and planar cross-strata predominate. Conglomerate lenses consist of gray to buff sand with pebbles of chert, quartzite and a few sandstone fragments. Some of the sandstone fragments appear to be from the Mesaverde Group. The intercalated mudrocks are generally gray and structureless. As with the Basal Unit, the cross-sectional profile is one of stacked, multilateral channel sandstones with small amounts of intercalated mudrock and conglomerate. The thickness in the study area varies from 0 to perhaps as much as 2400 feet (Weber,1964).

Fig. 2.4 - Channel sandstone in the basal Cub Mountain Formation

## QUATERNARY ROCKS

Two types of Quaternary sediments were mapped in the study. The most prominent type is alluvial valley fill. This is prevalent throughout most of the low-lying areas and on some of the higher terraces. In the western valley, a thick accumulation has covered practically the entire area. The thickness probably averages fifty feet and may reach as much as one hundred feet.

The second type of alluvium occurs along the upper flanks of Cub Mountain and was mapped as Quaternary landslides. These are thick colluvial aggregates or landslide deposits. They consist of a melange of cobbles and huge boulders in a sand-silt-clay matrix.

# DEPOSITIONAL ENVIRONMENTS

## MESAVERDE GROUP

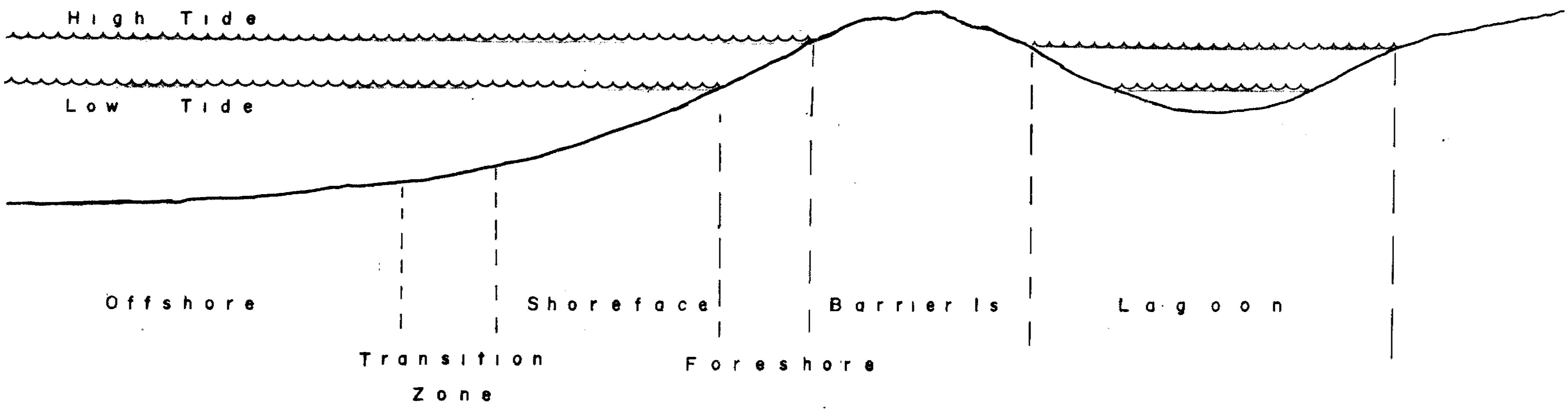
### Lower Sandstone Unit

The Lower Sandstone Unit shows characteristics of deposition in a marginal marine environment under regressive conditions. Exposures consist of shoreface and foreshore sediments with associated barrier island and eolian sands (fig. 3.1)

Petrologically, the clean, highly mature quartz sandstones are consistent with this environment. Textural parameters such as the fine grain size, high degree of sorting and rounding are typical of shoreline sediments (Dickinson and others, 1972). Composition is typical of shoreline sediments. Shorelines have such high energy and winnowing potential that only very stable constituents are apt to exist. In the Lower Sandstone Unit, only quartz is a major constituent. Other components such as feldspar and lithics are minor and clays have been winnowed out. These characteristics are typical of a marine shoreline deposit receiving little sediment influx from the continent.

In the lowest exposures, sediments are thinly bedded fine sandstone with some interbedded siltstone and shale. Horizontal laminae and low angle planar cross-strata predominate. These features represent some of the characteristics of offshore and transitional zone sediments (Howard, 1972; Elliot, 1978).

**FIG. 3.1** Illustration of coastal sub-environments
(after Elliot, 1978)



Throughout most of the sequence, the sediments are shoreface and foreshore deposits. Sedimentary structures range from horizontal laminae to medium angle planar cross-strata. Minor ripple marks and trough cross-strata occur. Bioturbation is moderately common. These features are characteristic of shoreface to foreshore environments (Howard, 1972; Elliot, 1978; Visher, 1965; Selley, 1978). Trace fossils include _Ophiomorpha_ and _Thallassinoides_ (?); both are common in marginal marine environments (Hantzchel, 1975). Only robust fossil fragments are found in this unit, mainly shell prisms of _Crassostrea soleniscus_. This is typical of a high energy, shoreline deposit (Potter, 1967).

At the top of the Lower Sandstone Unit are barrier island and eolian dune sediments. These have petrological features similar to the shoreface-foreshore sediments. However, sedimentary structures indicate a more landward environment. Erosional features are abundant as indicated by sharp, erosional bedding contacts. Cross-strata are generally planar, low to medium angle. At the top of the sequence are sediments interpreted as paleodunes (fig. 2.2). This interval exhibits features characteristic of eolian dunes as outlined by Bigarella (1972). They are very well sorted, well rounded quartz sandstones lacking any heavy minerals or fines. In addition, they have large-scale (ten to fifteen feet long) planar cross-beds dipping landward at angles over 22 degrees.

Overlying the Lower Sandstone Unit are lagoonal and lagoonal fill sediments of the Transitional Unit. Underlying the unit are open marine sediments of Mancos Shale. This provides further evidence of a regressive shoreline sequence.

As noted in the discussion of stratigraphy, the Lower Sandstone Unit exhibits some distinguishing overall trends. A general increase in energy level is noted upward in section as indicated by an overall increase upward of grain size and magnitude of sedimentary structures. This is characteristic of a regressive, marginal marine environment.

Further evidence lies in the shape of the unit. The gross morphology of the unit is that of an elongated sand body with consistent thickness and little variation along strike. Individual beds are continuous, vary little in thickness and exhibit rectangular vertical profiles. The resulting consistency and shape of the unit are indicative of marine shoreline deposits (Potter, 1967).

## Transitional Unit

The Transitional Unit is so named because it marks a transition from marginal marine to continental coastal plain sediments. The unit contains sediments of continental, restricted marine and marine origins deposited as tidal flats, lagoonal fill, fluvial channels and deltas. Figure 3.2 illustrates the general environment.

The diverse origins of the Transitional Unit are perhaps best exhibited by carbonaceous debris and fossils.

Thin coal seams and rootlets indicate a continental setting. The existence of high concentrations of *Flemingostrea aff. prudentia* indicates brackish water (Baker, 1981). Marine conditions are indicated by the presence of marine fossils, notably *Cymbophora sp.*, *Cyprimeria sp.* and an ammonite (*Placenticeras* ?).

The location of the unit with respect to surrounding strata indicates a coastal environment. The Transitional Unit is underlain by a regressive marine shoreline deposit and overlain by coastal plain sediments.

The lower portions of the unit exhibit features of lagoonal pond deposition as outlined by Selley (1978) and Masters (1967). General lithologies are interlaminated claystones, siltstones and some fine sandstones. Sedimentary structures are generally horizontal laminations with some ripples. Bioturbation is moderate to intense. The interval contains fossil hashes with well preserved specimens, low species diversity, and abundant individuals. High concentrations of *Flemingostrea aff. prudentia* occur indicating brackish water.

Tidal flat sediments occur in the lower and middle portions of the Transitional Unit. Sediments are generally interlaminated siltstones and claystones with some fine sandstone. Sedimentary structures are predominantly horizontal laminae with some small wave ripple marks. Claystones are often carbonaceous and contain some coal

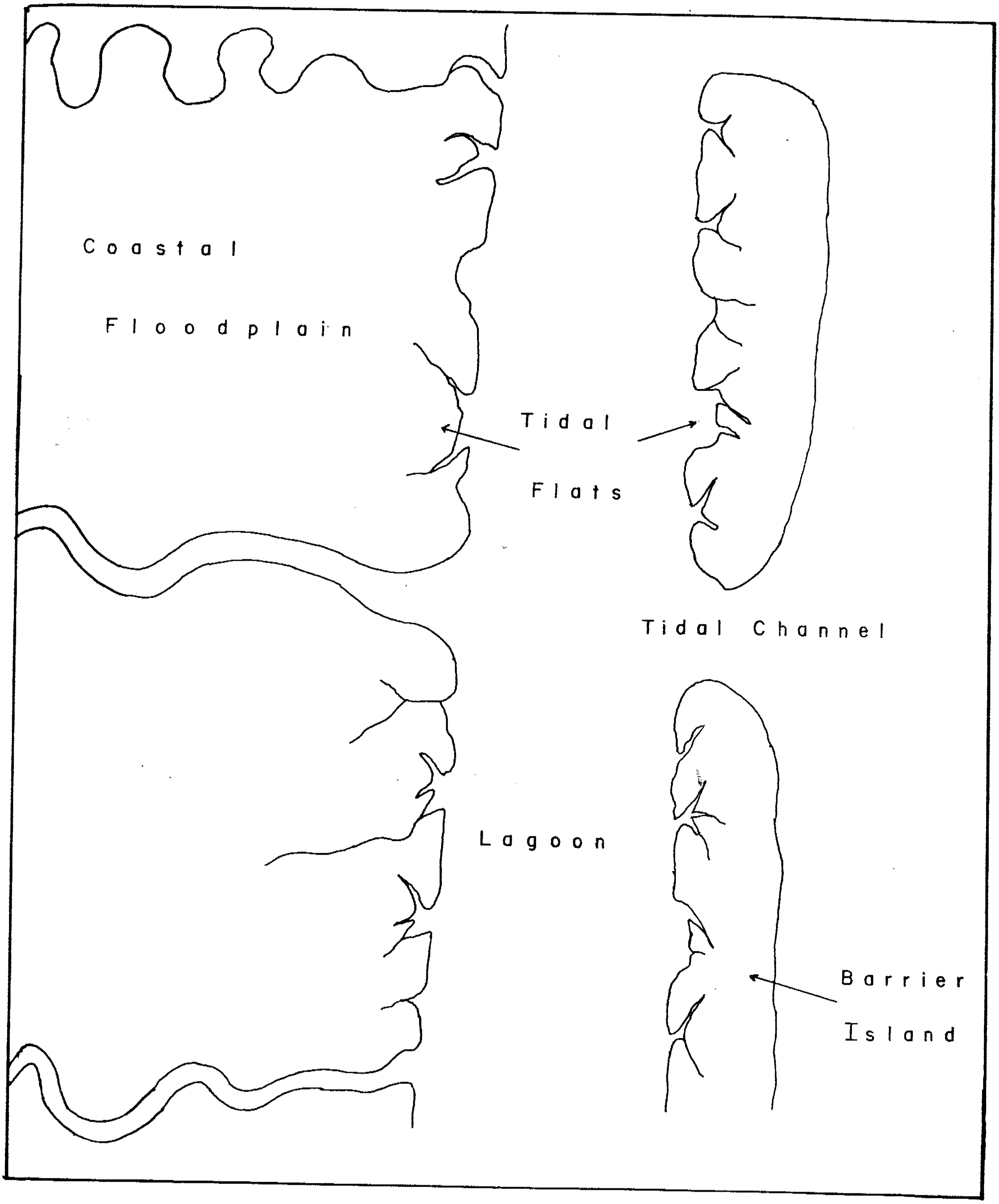


Fig. 3.2 Diagram of lagoon showing barrier island and coastal floodplain

(adapted from Selley, 1978)

stringers. Plant fragments and rootlets occur in abundance. These features are indicative of the shallow water and subaerial conditions that characterize tidal flats (Reineck, 1972; Masters, 1967; Selley, 1978).

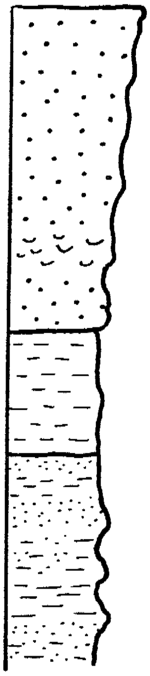
Throughout the Transitional Unit sandstone bodies are interbedded with and cut the finer sediments. These are interpreted as fluvial channels and deltas. The sandstones are structureless or show trough and low to medium angle cross-bedding. Locally, coarsening upward sequences occur. The shape is generally lenticular, although some persist for long distances (1 to 2 miles) with little thickness variation. The sandstones show a wide range in composition and texture. Pertinent to depositional environment are the abundance of feldspar, rock fragments and clay matrix, and the poor to moderate degree of sorting. Unstable constituents such as chloritized rock fragments and carbonaceous debris are present. These submature compositional and textural features indicate a nearby source and deposition in an environment with little reworking capabilities. The few sandstone bodies that occur in the lower and middle portions of the unit are interpreted as fluvial channels and deltas cutting tidal flats and infilling lagoons. In the upper portions of the Transitional Unit sandstones show the same deltaic characteristics; however, they exhibit definite marine features. These are large, slightly lenticular sandstone bodies with some interbedded mudrock lenses. Marine fossils are present in abundance (table 2.1). Contrary to the lower portions of the unit, this interval lacks any continental or restricted marine characteristics. Thus, the upper portions of the Transitional Unit represent a return to marine conditions, specifically, a deltaic shoreline. Lack of an underlying marine shale indicates the change in environment was not profound; rather, this was probably the tail end of a minor transgression. Figure 3.3 shows an interesting documentation of the change in environment. This section shows lagoonal sediments overlain by a carbonaceous claystone which is in turn overlain by an upward coarsening sandstone containing marine fossils.

## Barren Member

The Barren Member is interpreted as having been deposited in a coastal plain environment. This plain consisted predominantly of interchannel floodplain and paludal areas cut by a few sluggish, meandering streams.

Examination of the Barren Member with respect to surrounding units indicates a coastal plain setting. Beneath the Barren Member are prograding marine shoreline and lagoonal sediments. Overlying the unit are continental floodplain and meandering stream sediments of the Coal-Bearing Member. This occurs in an overall regressive sequence in which a landward progression of paleoenvironments occurs upward.

Fig. 3.3 Marine deltaic sediments overlying lagoonal–tidal flat sediments



| | |
|---|---|
| Upward coarsening sandstone, lenticular shape.<br>Contains broken, transported fossils, including an ammonite. | Marine Facies |
| highly carbonaceous black claystone | Tidal flat & lagoonal facies |
| Interlaminated mudrocks & fine sandstone, with horizontal laminae & ripple marks.<br>Intense bioturbation locally. | |

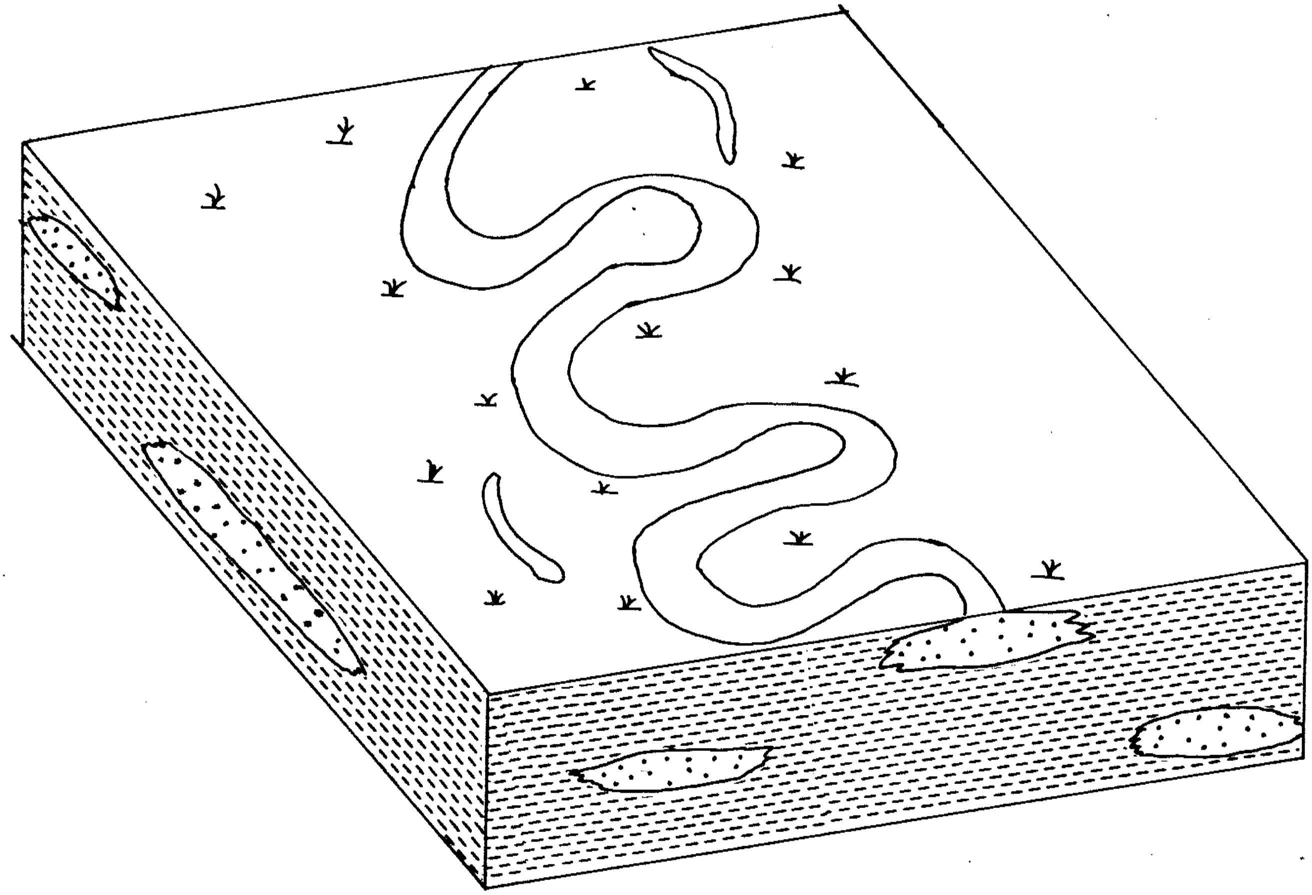


FIGURE 3.4

High sinuosity meandering stream profile (after Allen, 1965)

Strata in the Barren Member are all discontinuous and exhibit lateral and vertical facies changes. The cross-sectional profile shows a few lenses of sandstone surrounded by claystone and siltstone. Vertical sections show repeated fining upward cycles. The geometry of the strata and the cross-sectional profile indicate a floodplain environment cut by slow moving, high sinuosity meandering streams (fig. 3.4; Allen, 1965; Walker and Cant, 1979). The predominance of interchannel mudrocks is typical of coastal plain deposits (Selley, 1978; Reineck and Singh, 1975).

Sandstones are characterized by submature mineralogy and texture. They contain abundant feldspar, rock fragments and matrix, with fine grained, poorly to moderately sorted textures. Primary sedimentary structures are generally horizontal laminae with some trough and planar cross-beds. Although not unique to any one environment, the petrology and sedimentary structures are typical of low energy meandering streams. Mudrocks are generally flat-bedded or structureless and are often carbonaceous. These characteristics are common for floodplain deposits (Masters, 1967).

The position with respect to surrounding units, shape of strata, facies relationships and petrology all indicate deposition in a marginal continental, coastal floodplain. The setting is pictured as a widespread area of low relief cut by a few stream channels.

## Coal-Bearing Member

The Coal-Bearing Member exhibits much the same characteristics as the Barren Member and is essentially a continuation of the coastal plain depositional environment. In contrast to the Barren Member, which is predominantly claystone, the Coal-Bearing Member is dominated by sandstone. The increase in the volume of sandstone bodies stems from an increase in stream activity indicating the coastal plain was fluvially dominated.

Evidence for paleoenvironment follows the same general reasoning as with the Barren Member. The sequence is underlain by coastal plain sediments and overlain by braided stream deposits. Strata are typically lenticular and exhibit gradational facies changes. The submature sandstone petrology is typical of fluvial rocks.

Sandstones exhibit mostly trough cross-bedding with some low to medium angle planar cross-bedding. Current ripple marks and fining upwards sequences occur sparingly. Erosional and scour bases are common. As with the Barren Member, mudrocks are typically structureless or flat-bedded. These sedimentary structures indicate fluvial and floodplain origins (Ethridge, 1981; Selley, 1978; Masters, 1967).

The abundance of carbonaceous material definitely indicates continental origins. Plant fragments and rootlets are common. Carbonaceous debris occurs in a variety of rocks. Abundant coal indicates a setting with poorly drained low-lying areas accumulating peat. Most of the coal beds are shaly, indicating periodic inundation of the swamps.

As noted previously, the cross-sectional profile through the Barren Member shows largely overbank sediments cut by high sinuosity channel deposits. Stream activity was low and interchannel sedimentation dominated the interval. The lower portions of the Coal-Bearing Member exhibit similar features. However, upward in section, sediments show effects of increased stream activity: relative proportions of channel sandstone to interchannel mudrocks increases, sandstones show good lateral continuity, abundance of channeling and scouring increases and coals show poor development. These features indicate lower sinuosity, more vigorous streams (fig. 3.5; Allen, 1965). Thus, the sedimentary profile shows an increase in stream gradients and stream activity upward in section. Increased stream gradients and energy levels are attributed to continued regression of the Late Cretaceous sea and/or the beginning of uplift in the area. Both effectively create a drop in the base level of streams. Although still essentially a coastal plain environment, progression towards a more landward setting is indicated. These features indicate the Coal-Bearing Member was deposited on a fluvially dominated coastal plain and records a transition from coastal plain deposition to continental fluvial deposition.

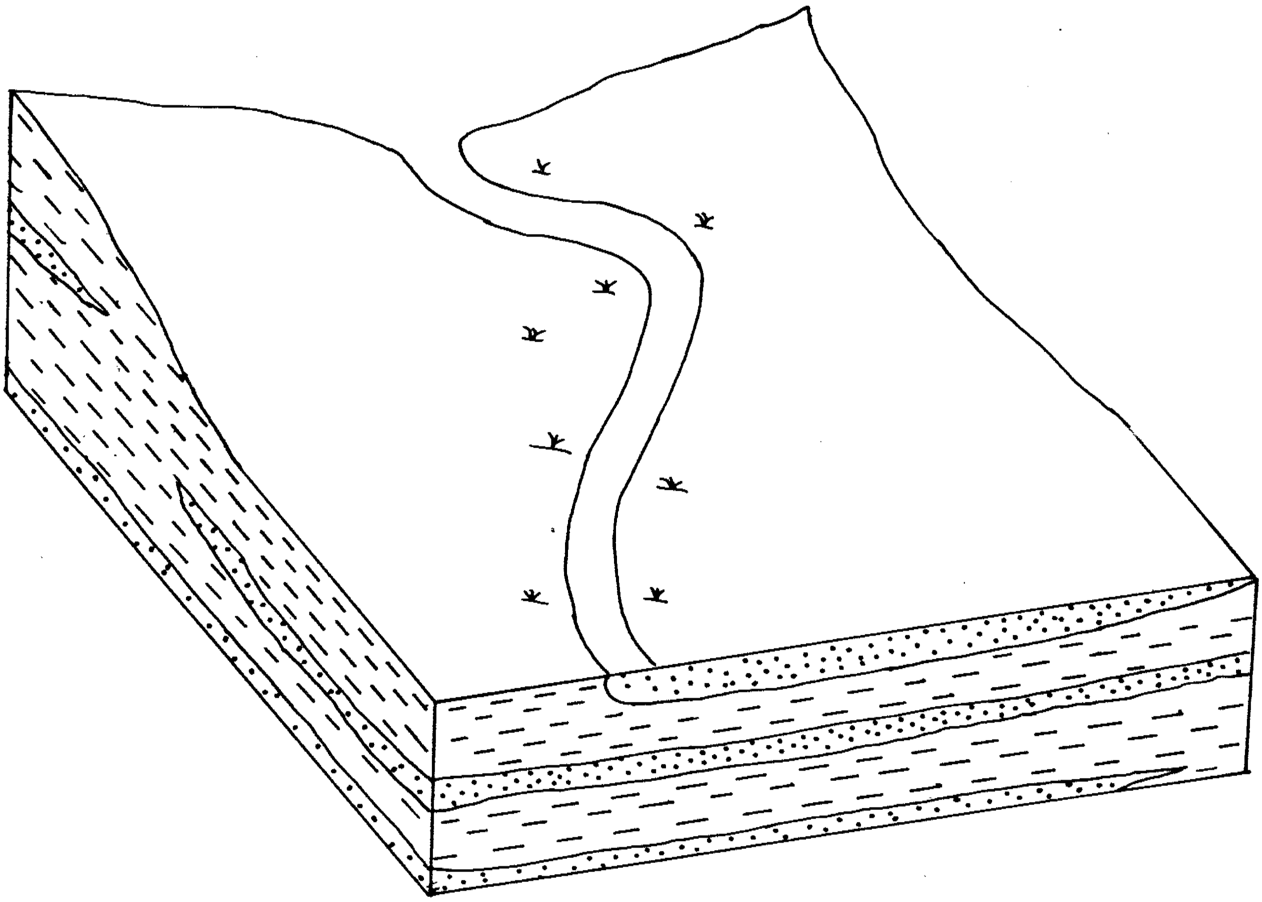


FIGURE 3.5

Low sinuosity meandering stream profile

(after Allen, 1965)

# CUB MOUNTAIN FORMATION

## Basal Unit

The Basal Unit is interpreted as having been deposited in a fluvial environment, borderline between true meandering and true braided stream environments. In a general sense, fluvial environments occur in two extremes: braided and meandering systems. In between these extremes is a gradual transition from one type to the other, resulting in different degrees of "blending" of the individual characteristics. This intermediate system has been called a "sandy braided stream" (Walker and Cant, 1979) or a "Platte Type" braided stream (Ethridge, 1981).

The position of the unit with respect to other units presents one line of evidence. The unit lies between meandering and braided stream environments in an overall setting that indicates landward progression of environments and increased relief. A cross-section through the sediments shows stacked sandstone lenses with some interbedded mudrock, typical of braided streams (Walker and Cant, 1979). Rarely, the channel sands can be seen to grade laterally into finer sediments (fig. 2.4). Scour bases are common; often these show signs of rip-up, including clay clasts and coal fragments. By far the predominant primary sedimentary structures are large troughs (up to 3-4 ft. in thickness) and medium angle planar cross-beds. These erosional features and sedimentary structures are consistent with braided streams (Ethridge, 1981).

Sandstones are typically medium grained and moderately to poorly sorted with subangular to subrounded grains. Although predominantly composed of quartz, they contain considerable rock fragments and feldspar, and some mica. Unstable inclusions are common, particularly clay clasts and coal. The composition and texture are consistent with a braided stream environment where sporadic high energy currents carry large sediment loads yet lack the ability to remove fines and unstable constituents.

Thus, the Basal Unit of Cub Mountain Formation represents a transition from the coastal plain meandering stream environment of the underlying Coal-Bearing Member to a braided stream environment. The transition resulted in a gradual upward change in lithology towards more arkosic, more angular and generally less mature sandstones of the main Cub Mountain Formation. The trends follow the pattern initiated in the Continental Unit, that is, the tendency toward increased stream gradients and energy levels upward in section. However, the increase becomes more profound through the Cub Mountain sediments, leading to braided stream conditions. This change no doubt signifies increased erosion and stream sediment load, probably resulting from uplift in the source area.

## Main Body of Cub Mountain Formation

The depositional environments of the upper portions of Cub Mountain Formation were not studied in detail. From brief studies during field work it is apparent that the unit is primarily a braided stream deposit. The unit exhibits many classical features of braided streams. The vertical profile shows stacked and multilateral channel sandstones with small amounts of interbedded conglomerate, siltstone and claystone. Sandstones are typically arkosic, medium to coarse grained and angular, exhibiting predominantly trough and medium angle planar cross-bedding. Scour bases and rip-up clasts are common. In addition, the position with respect to other units indicates a braided stream environment. The unit overlies meandering and "Platte Type" braided stream deposits in a transitional sequence from coastal to continental sedimentation. Thus, the formation is considered to be a braided stream deposit, probably resulting from Late Cretaceous-Early Cenozoic orogenic disturbances.

# IGNEOUS ROCKS

Igneous rocks in the study area were not analyzed in detail. Work was limited to mapping their occurrence and hand specimen identification. The area contains two major intrusives and numerous other dikes and sills. Intrusives cut sediments of the Cub Mountain Formation and are offset by mid-Tertiary faulting; thus, an early Tertiary age is indicated (see chapter 6).

The most prominent feature is a large sill capping Willow Hill. This is 100 to 150 feet thick and dips east-southeast at about 20 degrees. The sill is a porphyritic syenite consisting of coarse phenocrysts of albite, hornblende, augite and biotite set in a predominantly plagioclase groundmass. Slight textural and mineralogical variations are apparent within the sill.

The second major intrusive is a small syenite stock forming the core of Cub Mountain. This is similar in composition to the Willow Hill sill though it contains more potassium feldspar. The stock has a coarse-grained, phaneritic texture, with large plagioclase, hornblende and augite crystals set in a slightly finer mass of potassium feldspar, plagioclase and miscellaneous mafic minerals. Weber (1964) noted the occurrence of some nepheline in this intrusive.

Based on composition, texture, intrusive style and position, it is apparent that the Willow Hill sill and the stock at Cub Mountain are not intimately related. However, the similarity in composition and age suggests that the two may have originated from the same magma source and the plug-like stock may have been a feeder intrusive for the sill. Faulting has uplifted the sill relative to the stock so their relationship cannot be determined.

Another prominent feature is a small laccolithic (?) intrusive at west-central Willow Hill. This is a very fine-grained felsic rock, probably a syenite. Though exposures are limited, this intrusive appears to be more extensive underground and is probably related to the small anticlinal structure north of it (plate 1).

In the western valley, basalt sills cap the prominences known as Jake's Hill and Polly Hills. Otherwise, poor exposure and thick valley fill obscure most of the bedrock in this area making it difficult to determine how much intrusive activity is present. Some dikes were noted and judging from the general characteristics of the study area, more small intrusives probably occur at depth.

Numerous minor sills and dikes cut the incompetent sediments of the Mesaverde Group (plate 1). The majority are mafic, generally basalt. Lesser volumes of intermediate and felsic intrusives are present. The majority of the dikes seem to trend roughly east-west.

To summarize, the study area has had a significant amount of intrusive activity. Though all are probably related to the same series of events, intrusive style and rock type vary widely. The intrusives have played a minor role in the structural evolution of the area. Most have had relatively calm emplacement and have caused only localized structural features. In addition, where intrusives were emplaced close to coal seams (as at Willow Hill), the quality of coal appears to have been improved.

# STRUCTURAL GEOLOGY

The general structure of the Sierra Blanca area is that of a major basin intruded by a large igneous complex. The study area lies along the western fringe of the Sierra Blanca Basin where the general dip of bedding is 15 to 20 degrees southeast. The structure is complicated by localized faults and small to medium sized intrusives. This has resulted in considerable deviations from the normal strike and dip. Plate 1 indicates the major structural features of the area.

Two major faults occur within the study area. The most prominent strikes approximately north-south along the western portions of Willow Hill and Cub Mountain. This is a normal fault, downthrown on the west, dipping approximately sixty to seventy degrees west. Displacement is estimated at 100 feet. The second large fault occurs along Willow Draw. Exact faulting relationships are obscure due to alluvial cover. The fault is downthrown on the south side. The offset by the northerly trending fault indicates it has an earlier age, normal faulting and a southerly dip. Displacement increases slightly to the west, indicating slight hinge faulting. At cross-section BB' (plate 2) displacement is estimated to be on the order of 250 feet. The study area also contains numerous minor faults. Most seem related to intrusives or are intimately associated with the major faults.

A monocline with an east-west axis is a prominent structural feature on south Willow Hill. This feature causes a sharp change in dip from the normal southeastward direction of Willow Hill to due south. This is similar to dips on Cub Mountain and may be related to the fault in Willow Draw. Cross-section BB' (plate 2) illustrates the nature of this monocline.

A small anticline is present through the northwest portion of Willow Hill (plate 1). The arching has yielded abrupt changes in dip and slight displacement (about 5 feet) of beds along the apex. The origin of this structure is not clear; however, it is suspected to be a product of localized doming by the laccolithic (?) intrusive nearby.

In the flatlands along the western part of the study area, alluvial cover precludes observation of faults. Geologic mapping and some routine trigonometric calculations indicate the existence of an abnormally thick section of Mesaverde Group throughout the western valley. The possibility of folding is ruled out because all dips in the vicinity have a southeast orientation. To explain the anomalous thickness, considerable faulting and a large total displacement are required. Cross-section CC' (plate 2) is a hypothetical cross-section illustrating this point. The cross-section was drawn with little surface control and no subsurface information and is therefore highly speculative.

However, the basic point is irrefutable: to fit 800 feet of Mesaverde Group within a distance of over 2.5 miles at 15 to 18 degrees dip requires a series of faults.

Along the steep upper reaches of west Willow Hill, slump blocks are a prominent feature. The degree of slumping and size of the blocks varies widely. Although not a major feature, the slumping tends to add complexity to the stratigraphy and general geology of the middle Mesaverde units.

In general, the study area shows only moderate structural complexities. Strata are characterized by medium angle dips and fairly consistent profiles. Faulting is not intense and with a few exceptions, displacement is generally small. Folding is not present except for a slight doming of sediments on west-central Willow Hill, apparently the result of an intrusive. Other intrusives in the area have had very little effect on the structure.

# DISCUSSION AND GEOLOGIC HISTORY

The Cretaceous and Tertiary sediments in the Cub Mountain area show a well defined regressive sequence beginning with marine conditions and ultimately terminating in an intercontinental environment. Approximately 90 million years ago, during middle to late Turonian, large portions of New Mexico and western North American were covered by shallow seas (fig. 6.1; Williams and Stelck, 1975). In the Sierra Blanca area, marine sediments of the Mancos Shale were deposited. By late Turonian to early Coniacian, the seas began to regress. In their wake, marginal marine sediments of the Lower Sandstone Unit were deposited. Continued regression brought about lagoonal conditions as recorded in the lower portions of the Transitional Unit. This period was followed by a minor transgression causing a return to coastal marine conditions. The deltaic sediments of the upper Transitional Unit were deposited; subsequently, the seas returned to their regressive pattern.

Following the retreat of marine conditions, sediments of the Continental Unit were deposited along the coastal plain. Deposition of the Barren Member occurred along a low-lying floodplain cut by a few sluggish streams. As time progressed, the sluggish, high sinuosity meandering streams gradually changed to more vigorous, lower sinuosity meandering streams. This change was presumably a function of

Fig. 6.1 Extent of late early Turonian seas (from Williams & Stelck, 1975)

continued regression and slightly higher relief. Either regression or uplift would cause a drop in the base level of streams resulting in increased stream gradients. Higher energy levels and increased sediment influx are recorded in the fluvially dominated strata of the Coal-Bearing Member. Early in this transition, swamps formed. For the most part, these were of limited areal extent, received substantial detrital influx and had relatively unstable borders. As the transition towards increased gradients and more landward environments continued, the area became the site of predominantly meandering stream deposition, exemplified by deposits of the upper Coal-Bearing Member.

By early to middle Campanian, the Sierra Blanca area was considerably inland from the Cretaceous seaway (fig. 6.2; Williams and Stelck, 1975). By this time the area had undoubtedly experienced some uplift. As stream gradients and sediment load increased even further, the environment changed to braided stream conditions. At this point, sediments of the Cub Mountain Formation were deposited. As uplift continued, stream gradients and rate of erosion increased. This trend is recorded in the transition towards more arkosic, less mature sandstones upwards in the Cub Mountain Formation.

Since no unconformities exist in the study area, the above discussion suggests an early to mid-Campanian age for

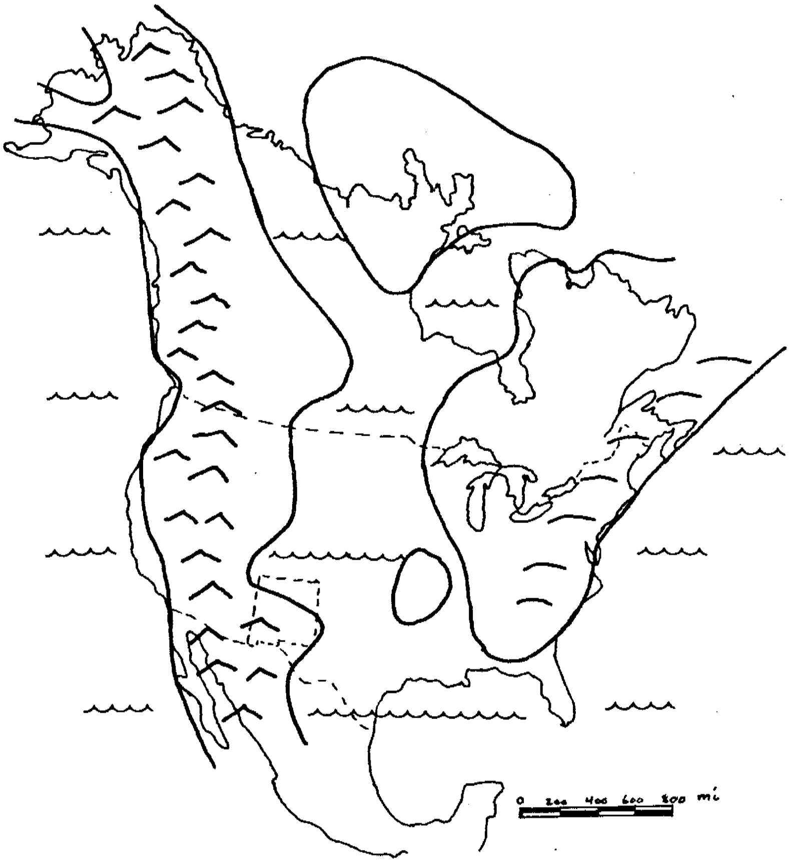


Fig. 6.2 Extent of mid-Campanian seas (from Williams & Stelck, 1975)

the uppermost Mesaverde or lower Cub Mountain sediments. Since Cub Mountain sediments reflect active uplift in the area, it it reasonable to assume deposition of the Cub Mountain Formation began when the first large-scale effects of the Laramide Orogeny were felt. Kelley and Thompson, (1964) suggest a late Montanan (Campanian to early Maestrichtian) time for this event. Thus, a late Cretaceous (Campanian or at least Maestrichtian) age is strongly indicated for the initiation of Cub Mountain Formation sedimentation.

Basinal subsidence and deposition of Cub Mountain Formation continued into the Tertiary. Weber (1964) suggests an Eocene age for the upper limit of Cub Mountain deposition. Allen and Kottlowski (1981) suggest an age as early as Paleocene. At any rate, a long period of erosion ensued after deposition of Cub Mountain Formation (Kelley and Thompson, 1964; Allen and Kottlowski, 1981). The erosion was considerable throughout the region, resulting in the removal of all Cretaceous rocks from the area, except those downfolded into the Sierra Blanca Basin. This suggests that the major formation of the basin was complete by this time.

The intrusion of the Sierra Blanca igneous complex occurred throughout most of the Oligocene (Allen and Kottlowski, 1981). All intrusives in the study area are assumed to be of this age. This age assignment is supported by the fact that the igneous rocks cut and overlie Cub Mountain Formation.

The last significant event was regional faulting. Kelley and Thompson (1964) suggest a Miocene age, noting the faulting was post Laramide but pre-Basin and Range development. The larger faults in the study area (Willow Draw and west Cub Mountain-Willow Hill) are consistent with this age range. The Cub Mountain Formation is substantially offset on both faults (plate 1). At least two small dikes and the Willow Hill sill show displacement by faulting. This indicates a post-Oligocene age for all major faults in the study area.

The sequence in the Cub Mountain area shows a gradual progression toward more landward environments. The shallow, late Cretaceous sea began to regress during late Turonian. Subsequently, the area became the site of marginal marine and coastal plain sedimentation, depositing the Mesaverde Group. Continued regression and the beginnings of Laramide uplift brought about true continental sediments of the Cub Mountain Formation. During very latest Cretaceous and early Tertiary, orogenic activity formed the Sierra Blanca Basin, thus preserving Mesaverde and Cub Mountain sediments from the long period of erosion that followed.

# COAL RESOURCES

Coal resources of Cub Mountain and vicinity were studied from outcrop and subsurface drilling data. Log descriptions and geophysical logs were obtained for fifteen drillholes. Drillholes average two hundred to three hundred feet deep and have been strategically placed, though somewhat widespread, throughout the study area. The drilling information is of a proprietary nature and cannot be released. It must suffice to say that drillholes occur in all four subdivisions of the study area and that data are reliable and consistent enough to provide considerable aid in the interpretation of resources.

For the purposes of this discussion, the study area has been divided into four sections: Willow Hill, north Cub Mountain, west Cub Mountain and western valley (fig. 7.1). Each section has unique stratigraphic and resource characteristics.

## Willow Hill

The Willow Hill area is defined in figure 7.1. No minable coal exists within this section. Minor coals occur in the Transitional Unit and at the base of the Coal-Bearing Member. The remainder of the area is too low in the stratigraphic section and contains only barren strata. Coals of the Transitional Unit are of no importance in the

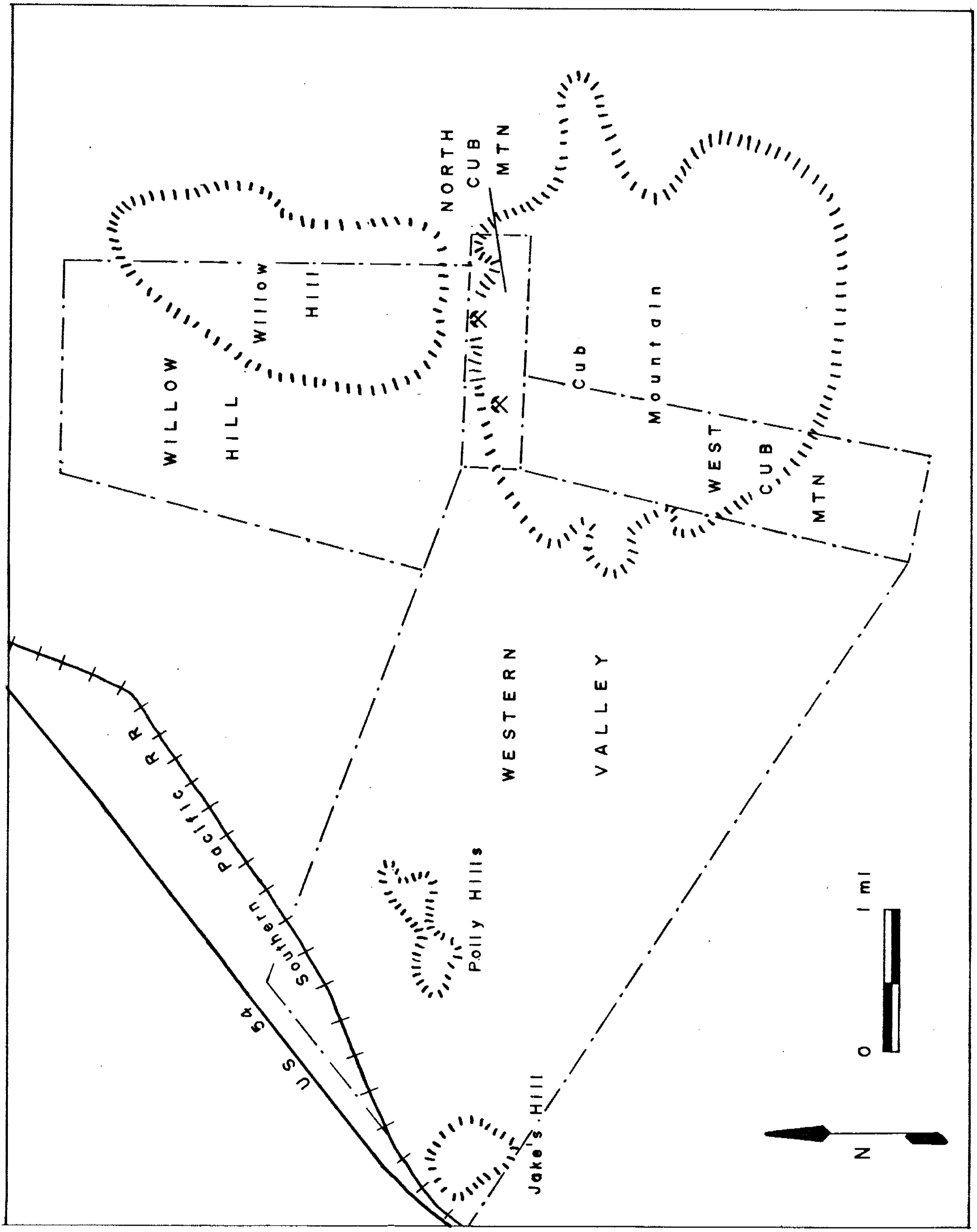


FIG. 7.1 - Index map of subdivisions for coal resource discussion

study area. These are discontinuous stringers, less than six inches thick. The coal apparently originated as small, localized peat accumulations along the fringes of lagoons or in tidal flats. These environments are not amenable to large peat accumulations; therefore, the Transitional Unit is not expected to contain minable coal. Near the top of Willow Hill is a one foot coal seam marking the base of the Coal-Bearing Member. The seam maintains good continuity and appears to have exceptionally good quality (due to the Willow Hill sill); however, it is too thin to be minable. In the past, some prospect pits were dug along west Willow Hill. Melhase (1927) reported that minable quantities of coal were not found.

## North Cub Mountain

The most interesting area from a standpoint of coal resources, occurs along the north face of Cub Mountain (fig. 7.1). Three coal-bearing horizons are present within the fluvial dominated strata of the Coal-Bearing Member (fig. 7.2). Resource analysis in this area is deduced mainly from observations made along outcrop and a series of prospect trenches. Four drill holes provide considerable subsurface information. Two other drillholes collared along the eastern periphery of the area provide further control.

The lower horizon (coal 2, fig. 7.2) is an overbank claystone sequence with two thin coal seams. Coals are wavy,

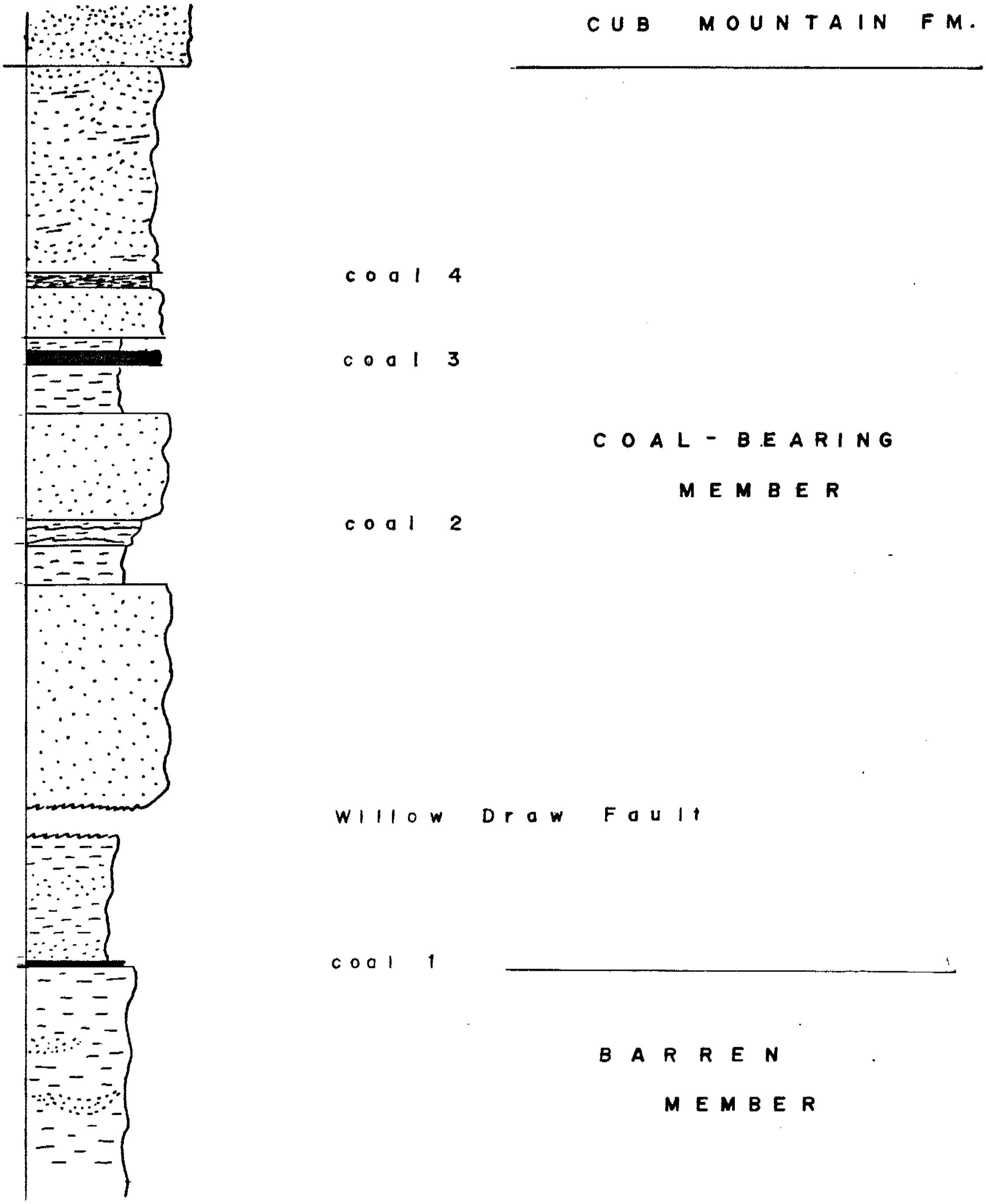


FIG. 7.2 - Generalized stratigraphic section through Coal-Bearing Member

discontinuous and commonly exhibit erosional surfaces. Thickness of the lower seam ranges zero to fourteen inches, averaging ten to twelve inches. The upper seam is usually about six inches thick but may pinch out completely. The thin, highly variant nature of the coals and the fluvial environment of deposition indicate the horizon has no resource potential.

The middle coal seam (coal 3, fig. 7.2) is 3.5 to 4.0 feet thick and continuous for about three-quarters of a mile along strike. Two drillholes indicate slight thinning of the seam with depth; 650 feet down-dip the seam is 3.0 feet thick and at 1000 feet from outcrop, 2.0 feet of coal persist. Coal quality appears good. The coal is black, vitreous to subvitreous, hard, blocky and has good cleat. Little to no foreign matter is present and there are no significant partings. Table 8.2 gives coal quality information on samples collected from the middle seam.

The upper horizon (coal 4, fig. 7.2) consists of about four feet of very shaly coal. The unit locally thins and grades into shale and sandstone. The coal-bearing portions appear to be a distal overbank deposit having considerable detrital influx. Coal in this horizon is considered unusable due to high clay content.

The resource potential of north Cub Mountain is adversely affected by steep dip, abrupt topographic relief and faulting. The dip of bedding ranges from 18 to 20 degrees. This, along with the steep topography, creates overburden ratios which eliminate any possibility of strip mining. In addition, the steep dip severely restricts the potential for underground mining. A few small faults are present on north Cub Mountain. Though faulting is relatively minor, it would pose problems to mining.

Table 7.1 shows demonstrated resources of the middle seam based on outcrop and drillhole data. Resources were calculated using procedures established in U.S. Geological Survey Circular 891 (Wood and others, 1983) for thicknesses 3.0 feet or greater, depth less than 250 feet, assuming bituminous rank. Calculations show a total demonstrated resource of 3.6 million tons. However, the recoverable fraction is considerably less. As noted, strip mining would not be feasible. Conventional underground mining could extract some 50 to 60 percent of the seam. However, the low values for seam thickness and total tons, combined with steep dip indicate that in all probability, underground mining would not be feasible. Under specialized marketing conditions, a small fraction of this resource may be recoverable using coal augers. Auger mining can extract 25 to 50 percent of the seam to distances of about 150 feet from the bench. Considering a 35 percent recovery rate, approximately 66,000 tons could be extracted by this process. Thus, for all practical purposes, only about two percent of the total demonstrated resource can be considered recoverable with present technology.

## TABLE 7.1
## Demonstrated Resources - North Cub Mountain

| | | Acres | | Tons | | |
|---|---|---|---|---|---|---|
| Control Pt. | Thick.(ft) | Meas. | Ind. | Meas. | Ind. | Total |
| Drillhole 1 | 3.0 | 97.0 | 480.0 | 523,800 | 2,592,000 | 3,115,800 |
| Outcrop 1 | 3.8 | 35.0 | - - - | 239,400 | - - - - - | 239,400 |
| Outcrop 2 | 3.5 | 44.0 | - - - | 277,200 | - - - - - | 277,200 |
| | | 176.0 | 480.0 | 1,040,400 | 2,592,000 | 3,632,400 |

Meas. = Measured
Ind. = Indicated
Thick. = Thickness

## West Cub Mountain

Along the western fringe of Cub Mountain (fig. 7.1), sediments of the Coal-Bearing Member outcrop or are near surface. Data on this area are limited. Very little of the Coal-Bearing Member is exposed. One drillhole provides some additional control; however, it is not in the most advantageous location. Coal was not encountered in either the drillhole or outcrop. This is somewhat surprising considering the abundance of coal along the north face of the mountain. However, most of the coal on north Cub Mountain, including the main seam, pinches out before the west Cub Mountain area. It appears the coal on north Cub Mountain has no direct relationship to the resources of west Cub Mountain.

Structure and topography place additional restrictions on the resource potential of west Cub Mountain. Small faults occur throughout the area. Steep dips (15 to 20 degrees) and abrupt topographic relief provide further obstacles to development. Furthermore, the fluvial dominated depositional environment indicates there is little potential for sizable coal deposits. Considering the structure and adverse depositional environment, it is very unlikely a minable deposit exists at west Cub Mountain.

### Western Valley

The western valley is defined as the flat, covered area west of Cub Mountain and Willow Hill to the edge of highway U.S. 54 (fig. 7.1). Sediments on Jake's and Polly Hills (plate 1) belong to the Lower Sandstone Unit. It follows that slightly east of here marks the western-most extent of the Coal-Bearing Member. Thus, although covered, the unit underlies the majority of the western valley.

The occurrence of the Coal-Bearing Member, gentle topography and the close proximity of a railroad, make the western valley an interesting area for potential coal development. Thick alluvial cover makes it difficult to determine the presence of coal and subsurface data is inconclusive. Four drill holes ranging one hundred to three hundred feet deep occur in the area. One foot of shaly coal was encountered in one drillhole. Other drillholes have been collared too high or too low in the stratigraphic section and did not penetrate the Coal-Bearing Member.

Although drilling and outcrop data are inconclusive, other geologic factors indicate that the western valley has little potential of hosting minable coal deposits. First, as with the entire Cub Mountain area, the depositional environment was poorly suited for accumulation of minable coal deposits. Secondly, structural problems present major obstacles to coal mining. As previously discussed, the extraordinary thickness of Mesaverde Group indicates significant faulting in the area. In addition, dips of 15 to 18 degrees severely limit the possibility of strip-mining. Further restricting the resource potential is the depth to the Coal-Bearing Member. As illustrated in cross-section CC' (plate 2A), only small, isolated blocks of coal are apt to occur within stripping range. Thus, whether or not coal is present in the western valley, depositional environment, structure and depth to the coal zone indicate that the potential for finding a minable deposit is low.

# DISCUSSION

Certain characteristics of coal in this study area severely limit the potential for development. The most important limiting factors on coal development are sub-economic thicknesses and discontinuity. Seam thicknesses are under four feet. In the Sierra Blanca area, under present economic and technologic conditions, there is little potential for developing seams under four feet. More importantly, discontinuity of the seams severely restricts total tonnages. The majority of discontinuity is a primary depositional feature. Studies indicate the coals formed on a fluvially dominated coastal plain. The predominance of streams leads to major constraints on peat accumulation. Stream activity tends to destroy peat accumulations, increases detrital influx into the swamps and leaves less area for swamp formation. The end result is the discontinuity, high shale content and low tonnages characteristic of coal in the study area. Another major problem is the steep dip of strata. This severely restricts the potential for coal mining. Finally, the presence of faults and intrusives must be considered. Though not abundant in the study area, faults and intrusives occur sufficiently often to be considered as potential mining problems.

Based on limited thickness and discontinuity of the coal, steep dip, and unfavorable depositional environment, the study area shows little potential for coal development. The western valley has not been explored to a high degree of confidence and it is possible the area may contain some coal. However, depositional environments indicate that deposits would be small and hard to find. More importantly, the steep dip virtually eliminates the feasibility of mining. The north Cub Mountain area might support a small-scale auger mining operation with reserves less than a million tons. However, because of the low tonnage and the availability of more competitive sources of coal, this would require somewhat unusual marketing conditions (e.g. a local need for coal).

## Potential Exploration Targets

In addition to detailed study in the Cub Mountain area, mines and prospects were examined near Oscura, White Oaks and Capitan. It seems appropriate to combine these observations with those made at Cub Mountain and project potential exploration targets for other parts of the Sierra Blanca field.

To begin with, in terms of a regional study, a second possible coal-bearing interval must be considered. The Barren Member was deposited immediately landward of the regressing sea on a coastal plain dominated by interchannel areas. Although barren in the Cub Mountain area, the depositional environment was well suited for peat accumulation. Thus, in other regions of the field this interval may contain minable concentrations of coal. By contrast, the Coal-Bearing Member can be expected to have low tonnages throughout the basin. The fluvial domination and more landward setting are considered to be regional features related to either regression or uplift. It follows that minable coal deposits would be best sought after in strata equivalent to the Barren Member.

A problem inherent throughout the Sierra Blanca Basin is the steep dip of strata. Along the fringes of the basin, where the Mesaverde is near surface, dips are generally greater than 15 degrees. In addition to steep dips, faulting and intrusive activity are common to many areas of the basin.

In the Capitan area, steep dips, faults and intrusives severely limit the potential for minable coal deposits. Furthermore, the area is about 20 miles from the railroad. The White Oaks area has the same structural problems as Capitan. Both White Oaks and Capitan were sites of active underground coal mining in the early part of the century. Although seams were thin and structurally complex, they were minable because of favorable market conditions. With the advent of diesel locomotives and competition from other, more cost-efficient mines, mining ceased. Based on structural problems and the current economics of the coal industry, it is doubtful that these areas could be mined at present.

Near Oscura, the geology seems much the same as the Cub Mountain area. Although information is limited, this area seems plagued with steep dips and considerable faulting. At present, two or three companies hold leases northeast of Carrizozo. Apparently these are marginal deposits and there are no current development plans. The plains east of Carrizozo probably exhibit features similar to Cub Mountain. Being closer to the center of the basin, dips may level out slightly. The plains northeast and east of Carrizozo may have some potential for minable coal deposits, especially small deposits. Considering large coal deposits (greater than 25 million tons), the data presented indicate there is little potential for finding an economically competitive deposit. In terms of locating large coal deposits this author would not recommend detailed exploration or drilling anywhere in the Sierra Blanca Basin.

# COAL QUALITY

Sierra Blanca coal is generally considered to be good quality, bituminous rank. Table 8.1 (Campbell and Roybal, unpublished data) gives coal quality data for Sierra Blanca coal in general. This data represents averages of 13 mine samples on record at New Mexico Bureau of Mines and Mineral Resources.

Table 8.2 gives coal quality data from two samples collected from mine dumps at Cub Mountain. Because the samples have been exposed on the surface for 50 to 60 years, results are essentially equivalent to having been tested on a dry basis. Moisture values are anomalously low; subsequently, heating values and ash contents are higher than would be expected in fresh samples.

The tables indicate that Sierra Blanca coal is characteristically low sulfur, medium to high ash and has relatively high heating value. The values indicate the coals are in the high volatile bituminous to high rank subbituminous range.

|  | No. | Avg. | Stand. Dev. | Max. | Min. |
|---|---|---|---|---|---|
| PROXIMATE (%) |  |  |  |  |  |
| Moisture | 12 | 6.24 | 4.99 | 13.90 | 1.20 |
| Ash | 12 | 14.40 | 5.30 | 24.90 | 8.50 |
| Vol. Matter | 12 | 33.01 | 3.84 | 37.90 | 25.10 |
| Fixed Carbon | 12 | 46.32 | 6.16 | 57.80 | 34.20 |
| ULTIMATE (%) |  |  |  |  |  |
| Moisture | 12 | 6.24 | 4.99 | 13.90 | 1.20 |
| Carbon | 12 | 61.36 | 8.18 | 71.20 | 45.70 |
| Hydrogen | 12 | 4.56 | 0.50 | 5.20 | 3.80 |
| Nitrogen | 12 | 1.17 | 0.16 | 1.40 | 0.90 |
| Sulfur (total) | 13 | 0.73 | 0.16 | 1.00 | 0.50 |
| Organic S | 6 | 0.50 | 0.16 | 0.76 | 0.26 |
| Pyritic S | 4 | 0.15 | 0.06 | 0.23 | 0.10 |
| Sulfate S | 3 | 0.11 | 0.17 | 0.30 | 0.01 |
| Ash | 12 | 16.13 | 6.88 | 30.60 | 8.45 |
| Oxygen | 12 | 13.37 | 6.04 | 26.10 | 7.70 |
| BTU | 13 | 10881 | 1807 | 12952 | 7061 |
| BTU (MMMF) | 13 | 12775 | 2210 | 15131 | 9123 |

TABLE 8.1 Analyses of Sierra Blanca coal (source: Campbell and Roybal, New Mexico Bureau of Mines and Mineral Resources)

| | West Adit | East Adit |
|---|---|---|
| PROXIMATE (%) | | |
| Moisture | 0.56 | 0.81 |
| Ash | 16.69 | 15.56 |
| Vol. Matter | 29.40 | 21.94 |
| Fixed Carb. | 53.35 | 61.69 |
| ULTIMATE (%) | | |
| Sulfur | 0.68 | 0.78 |
| BTU | 11,906 | 12,209 |

TABLE 8.2 - Analyses of samples from mine dumps at Cub Mountain (Tested at New Mexico Bureau of Mines and Mineral Resources, Coal Analysis Lab)

# SUMMARY AND CONCLUSIONS

Through much of the Sierra Blanca Basin, coal occurs in the upper horizons of the Mesaverde Group. In an attempt to gain knowledge of resources, this study examined stratigraphy, structure, depositional environments and coal occurrences of a portion of the field near Cub Mountain.

The Mesaverde Group contains three distinct stratigraphic units. The Lower Sandstone Unit is a thick, uniform deposit of clean quartz sandstone deposited along a regressive marine, barrier island shoreline. Conformably overlying this unit are 95 feet of sandstone, siltstone, claystone and shale belonging to the Transitional Unit. These were deposited in a coastal environment as lagoonal, tidal flat and deltaic sediments. Although data are inconclusive at present, the Lower Sandstone Unit and possibly the Transitional Unit may be correlative with Gallup Sandstone.

Conformably overlying the Transitional Unit are coastal plain sediments of the Continental Unit. This unit has been arbitrarily subdivided on the basis of gross lithologies into the Barren and Coal-Bearing Members. The lower Barren Member consists of 225 feet of claystone and siltstone with lesser volumes of sandstone. These are floodplain and overbank deposits with some intercalated stream channel deposits. The Coal-Bearing Member consists of about 260 feet of sandstone, siltstone, claystone and coal. These were deposited on a fluvial dominated coastal plain having a more landward setting than the Barren Member. Judging from the limited data at hand, it appears that sediments of the Continental Unit may be correlative with Crevasse Canyon Formation. Conformably overlying the Continental Unit are fluvial sandstones and mudrocks of the Late Cretaceous to Tertiary Cub Mountain Formation.

Coal resources were studied from surface observations and drillhole data. Coals show characteristics of deposition in a fluvially dominated environment. Seams are thin, discontinuous and often shaly. Dips of the coal-bearing strata are generally on the order of 15 to 20 degrees. In addition, faults and intrusives occur with sufficient frequency to pose potential problems to coal mining. Because of thin seams, discontinuity, steep dip and faulting, it is concluded that the study area could not support large-scale coal mining. However, under specialized market conditions, the area may support a small mining operation with reserves in the range of 1 to 3 million tons.

## Suggestions for Future Work

Knowledge of Upper Cretaceous strata in the Sierra Blanca Basin is generally limited. There is an obvious need for detailed stratigraphic work in this area and an attempt to correlate the lesser known units of the Sierra Blanca Basin with units elsewhere. The Cub Mountain Formation is still a poorly defined unit and needs detailed study to determine precise stratigraphy, age and possible correlations with units elsewhere in the state.

Though preliminary indications are discouraging, the coal resources of the Sierra Blanca Basin could be studied further. With detailed geologic and resource studies now available for the Capitan (Bodine, 1956) and Cub Mountain (this study) areas, it appears the most advantageous locations for study of this sort would be near White Oaks and the Three Rivers-Oscura area.

# APPENDIX - SELECTED MEASURED SECTIONS

## MEASURED SECTION 3 - Measured through Lower Sandstone and Transitional Units on west Willow Hill.

(NW 1/4 sec. 27, T8S, R10E)

### TRANSITIONAL UNIT

| | | |
|---|---|---|
| 3.16 | 1'3" | Gray-brown sandstone. Fine to medium grained, poorly sorted, subrounded. Qtz-fspar-cal-mafics. Dirty, arkosic. Well indurated; structureless. Similar to 2.15. |
| 3.15 | 1' | White sandstone. Medium grained, medium sorting, subrounded. Qtz-fspar-cal-clay. Friable. Thinly bedded w/ ripples; bioturbated. Similar to 2.14. |
| 3.14 | 8'6" | Covered. Possibly the friable sandstone above. |
| 3.13 | 4'6" | Gray-brown arkosic sandstone like 3.16. |
| 3.12 | 10'6" | Covered. Possibly friable sandstone. |

| | | |
|---|---|---|
| 3.11 | 10' | Buff sandstone. Medium grained, medium sorted, subrounded. Qtz-cal-rk frags-hi clay matrix. Some oyster fragments. Friable, laminated and highly bioturbated. |
| 3.10 | 5' | Covered. |
| 3.9 | 7' | Purple-black siltstone and very fine sandstone. Structureless and thinly bedded. |
| 3.8 | 3'6" | Buff sandstone. Medium grained, poorly sorted, angular. Qtz-cal-rk frags-minor clay. Friable. Parallel laminated and possibly bioturbated. |
| 3.7 | 3'6' | Gray-brown sandstone. Fine to very fine grained, poorly sorted, angular. Qtz-fspar-cal-clay. Well indurated. Structureless. |
| 3.6 | 4'9" | White Qtz sandstone. Med. grained, well rounded very well sorted. Almost all qtz. Minor fspar-cal-limonite. Well indurated. Structureless, possibly bioturbated. |
| 3.5 | 3'6" | Brown silty sandstone, oyster bed. |

### TOP OF LOWER SANDSTONE UNIT

3.4 12' White Qtz sandstone. Like 3.6. Horizontal and low angle planar cross-beds. Occasional burrows, one large oyster fragment.

3.3 7' White Qtz sandstone. Like 3.6. Low to medium angle planar cross-beds.

3.2 36' White Qtz sandstone. Like 3.6. Low angle planar cross-beds; some parallel laminations.

3.1 11'6" White Qtz sandstone. Like 3.6. Thinly bedded. Beds range from structureless to horizontally laminated to low angle planar cross-bedded. Includes shale partings with compaction folds and ripples.

### MEASURED SECTION 4 - Measured through Continental Unit
### on west Willow Hill
### ( NE 1/4, sec. 27, T8S, R10E)

### BARREN MEMBER OF CONTINENTAL UNIT

4.6 4' Gray-black shale.

| | | |
|---|---|---|
| 4.5 | 6'6" | Green mudstone. (Like 4.1 but finer grained) Qtz-rk frags in green clay matrix. Structureless. |
| 4.4 | 10' | Black and brown shale. |
| 4.3 | 4' | Gray sandstone. Medium grained, poorly sorted subrounded. Qtz-rk frags +/- fspar (?) in clay matrix. Thinly bedded and rippled. |
| 4.2 | 5'6" | Black shale. |
| 4.1 | 8'6" | Green sandstone (graywacke). Medium grained, poorly sorted, medium rounded. Qtz-fspar-rk frags -mafics in a high clay matrix.<br>Medium induration. Structureless. |

MEASURED SECTION 8 - Measured through middle of west Willow Hill (NW 1/4, sec. 34, T8S, R10E)

| | | |
|---|---|---|
| 8.37 | --- | Syenite. Contact of sill capping Willow Hill |

COAL-BEARING MEMBER OF CONTINENTAL UNIT

| | | |
|---|---|---|
| 8.36 | 7' | Covered. |
| 8.35 | 11' | Gray claystone. |
| 8.34 | 6'6" | Gray-green sandstone. Med. grained, med. sorted, subrounded. Contains qtz-cal-fspar-mafics; moderate amount of clay matrix. |
| 8.33 | 6' | Gray-black sandstone. Fine grained, well sorted, well rounded. Structureless to thinly bedded. |
| 8.32 | 1' | Coal. Weathered but hard and vitreous. |

TOP OF BARREN MEMBER OF CONTINENTAL UNIT

| | | |
|---|---|---|
| 8.31 | 22'6" | Black claystone. Carbonaceous at top. |
| 8.30 | 11' | Buff sandstone. Medium grained, subrounded, poorly sorted. Contains Qtz-cal-rk frags; high clay matrix. Structureless to horizontally laminated. |

| | | |
|---|---|---|
| 8.29 | 6" | Black claystone. |
| 8.28 | 3' | Gray sandstone. Very fine grained. Structureless. |
| 8.27 | 19'6" | Black and yellow claystone. |
| 8.26 | 13'6" | Buff sandstone. Med. grained, poorly sorted, angular. Contains Qtz-cal-rk frags. Moderate clay amount of matrix. Poorly indurated. Structureless. Contains some concretions and rootlets. |
| 8.25 | 14'6" | Black claystone. |
| 8.24 | 95' | Covered. (Contains float of grayish green and brown sandstone.) |
| 8.23 | 18' | Black claystone. |
| 8.22 | 8'6" | Gray sandstone. Fine grained, poorly sorted, angular. Contains qtz-rk frags-fspar; moderate clay matrix. Horizontal laminae and fine, low angle planar cross-beds. |
| 8.21 | 5'6' | Covered. |

| | | |
|---|---|---|
| 8.20 | 4' | Gray to brown sandstone. Fine grained, poorly sorted, angular. Contains qtz-rk frags-fspar-cal; weathers brown (limonite stained); limey concretionary layers. Some fossiliferous layers (unidentifiable fragments). Structureless to horizontally laminated. |

TOP OF TRANSITIONAL UNIT

| | | |
|---|---|---|
| 8.19 | 17' | Buff sandstone. Med. grained, med. sorted, subrounded. Contains qtz-fspar-rk frags-mafics(?)-cal. Medium induration. Horizontally laminated. |
| 8.18 | 5' | Black claystone. |
| 8.17 | 2' | Buff sandstone. (Same as 8.19.) |
| 8.16 | 2'3" | Gray sandstone. Weathers brown. Fine grained, poorly sorted, angular. Contains qtz-rk frags-fspar-mafics(?). Very little matrix. Medium indurated. Structureless. |
| 8.15 | 36' | Buff sandstone. (Same as 8.19.) |
| 8.14 | 11' | Black shale. |
| 8.13 | 14' | Buff sandstone. (Same as 8.19.) |

8.12 2'6" Brown fossiliferous sandstone - oyster bed. Fine to very fine grained, poorly sorted. Horizontally laminated to structureless with some ripples. Bioturbated.

TOP OF LOWER SANDSTONE UNIT

8.11 15' White quartz sandstone. Structureless, some low to med. angle planar x-beds.

8.10 1'9" Black shale.

8.9 1' Brown sandstone. Fine grained, medium sorted, subrounded. Contains qtz-rk frags. Moderate clay matrix. Finely bedded (horizontal and low angle cross-beds) and rippled.

8.8 3" Black shale.

8.7 4' Covered (shale?).

8.6 96' White quartz sandstone. (Same as 8.11.) Structureless to horizontally laminated to medium angle cross-bedded.

FAULT - Units 8.5 -8.1 repeat part of Transitional Unit

| | | |
|---|---|---|
| 8.5 | 9' | Covered. (Believed to be same white qtz sandstone as 8.6.) |
| 8.4 | 3'6" | Gray sandstone. Weathers brown. Med. grained, med. sorted, subrounded. Contains qtz-fspar- rk frags-cal-mafics. Well indurated. Laminated to structureless. Some fossil fragments and burrows. |
| 8.3 | 15'6" | Buff sandstone. Med. grained, poorly sorted, subrounded. Contains qtz-cal with minor lim-mafics. Moderate clay matrix. Medium indurated. Structureless to finely bedded; bioturbated. |
| 8.2 | 18'9" | Covered. |
| 8.1 | 12'3" | Black shale. Some interbedded very fine sandstone. |

## MEASURED SECTION 17 - Measured through parts of Lower Sandstone and Transitional Units on west Willow Hill

(SE 1/4, sec. 33, T8S, R10E)

### TRANSITIONAL UNIT

| | | |
|---|---|---|
| 17.8 | 26' | Black claystone. Some sandy lenses; some very thin (<4") and discontinuous coal stringers. |
| 17.7 | 39' | White Qtz sandstone. Same as 17.3 but fine grained. |
| 17.6 | 7' | Black claystone. Some sandy lenses; some very thin (<5") and discontinuous coal stringers. |
| 17.5 | 9' | Covered. Believed to be mostly black claystone. |
| 17.4 | 2' | Black claystone. |
| 17.3 | 3' | White sandstone. Subarkosic, very friable. Fine to med. grained, poorly sorted, subrounded. Contains Qtz-hi fspar-rk frags-cal. Structureless, possibly due to bioturbation. Unit is laterally discontinuous, thickens eastward and thins to the north and south. Contains plant fossils and rootlets. |

17.2 3' Brown sandy siltstone, fossil bed.

TOP OF LOWER SANDSTONE UNIT

17.1 14' White Qtz sandstone. Very clean, medium grained, well sorted and rounded. Almost all Qtz. Low angle x-beds at bottom, 2 ft. burrowed zone in middle, hi angle, very long (>10') x-beds at top (eolian ?).

MEASURED SECTION 9 - Measured through Coal-Bearing Member
of Continental Unit on north Cub Mtn.
(SW 1/4, sec. 3, T9S, R10E)

9.14 9' Black, tan and gray claystone with two small (<6") coal seams. Seams thin locally; one pinches out.

9.13 15' Covered.

9.12 3'6" Tan sandstone. Fine grained. Possibly stream channels.

| | | |
|---|---|---|
| 9.11 | 11' | Covered. (Partly tan sandstone.) |
| 9.10 | 5' | Buff sandstone (like 9.8). |
| 9.9 | 1'6" | Black claystone. |
| 9.8 | 9'6" | Buff sandstone. Medium grained, poorly sorted, angular. Contains qtz-fspar-cal-mafics. Little to no matrix. Horizontally laminated. |
| 9.7 | 1' | Red-brown graywacke (like 9.5). |
| 9.6 | 7' | Covered (possibly buff sandstone). |
| 9.5 | 3' | Red-brown graywacke (or arkosic mudstone). Fine to med. sand in mud matrix. Poorly sorted, subrounded. Contains qtz-fspar-mafics-limonite in cal-clay matrix. Structureless. |
| 9.4 | 4' | Covered (sandstone ?) with coaly shale at top. |
| 9.3 | 3' | Buff sandstone. Med. grained, moderately sorted, subrounded. Friable. Horizontally laminated. |
| 9.2 | 13' | Covered. |

| | | |
|---|---|---|
| 9.1 | 4'3" | Brown sandstone. Very fine grained, calcareous. Mostly structureless, but interval has some ripples and horizontal laminations. |

MEASURED SECTION 10 - Measured through Coal-Bearing Member of Continental Unit on north Cub Mountain.

(SW 1/4 sec. 3, T9S, R10E)

| | | |
|---|---|---|
| 10.10 | -- | Light-brown mudstone. Planar cross-bedded. |
| 10.9 | 20' | Buff sandstone w/ limey concretionary (?) layer at top. |
| 10.8 | 7' | Covered. Possibly claystone. |
| 10.7 | 4' | Gray sandstone. Medium grained, poorly sorted Fine, parallel beds. |
| 10.6 | 29'6' | White and tan sandstone. Fine-medium grained, medium sorting, subrounded. Contains qtz-fspar-cal-clay-some mafics. Mostly structureless and thinly bedded. |

| | | |
|---|---|---|
| 10.5 | 6'6" | Tan and gray sandstone. Fine grained, poorly sorted, angular. Contains qtz w/ high clay, very little calcite. Contains concretionary layers and nodules. Very friable. Horizontal, parallel bedded. |
| 10.4 | 5' | Gray siltstone w/ plant fragments and sandstone interbeds. (Nat'l levee ?) |
| 10.3 | 3'7" | Coal, main seam. |
| 10.2 | 14'6" | Covered (...by rock pile from test trench). |
| 10.1 | 28'6" | Light gray sandstone. Medium grained, well sorted, angular. Contains qtz w/ minor rk frags-fspar-lim-clay. Well indurated. Structureless and finely bedded. Stained brown (Fe) at bottom. |

BASE: Claystone with interbedded coal (correlates with 9.14).

MEASURED SECTION 11 - Measured through Coal-Bearing Member of Continental Unit into Cub Mountain Fm. on North Cub Mtn.

(SE 1/4, sec. 3, T9S, R10E)

| | | |
|---|---|---|
| 11.15 | -- | Quaternary talus |

CUB MOUNTAIN FM.

| | | |
|---|---|---|
| 11.14 | 51' | White and buff sandstone. Medium-coarse grained, subangular, medium sorted. Contains qtz w/ fspar, minor cal-lim-rk frags. |
| 11.13 | 5'6' | Conglomerate. Rounded stream pebbles, 1/4" to 4" dia. in buff, sandy matrix. Pebbles include chert and quartzite. |
| 11.12 | 191' | Tan and white sandstone. Fine-medium grained, subangular to angular, poor-medium sorting. Contains qtz-fspar-rk frags-cal-lim. Friable. Some small shale layers. Structureless, planar and trough cross-bedded. |
| 11.11 | 5' | Covered. |
| 11.10 | 4' | Black and yellow claystone; sandstone interbeds. |
| 11.9 | 2' | Covered. |

| | | |
|---|---|---|
| 11.8 | 6' | White to buff Qtz sandstone. Medium grained, subrounded, well sorted. Qtz w/ minor fspar-cal-rk frags. Structureless, planar and trough cross-bedded. (very similar to Lower SS Unit.) |

TOP OF MESAVERDE GP. (COAL-BEARING MEMBER)

Contact sharp and conformable.

| | | |
|---|---|---|
| 11.7 | 10' | Buff and dark green sandstone. Fine grained. Poorly exposed. |
| 11.6 | 2'9" | Tan sandstone. Medium grained, angular, poorly sorted. Qtz-cal-mafics. Laminated and rippled. |
| 11.5 | 6' | Black claystone, tan at top. Contains concretion layers and nodules. |
| 11.4 | 2' | Light brown arkosic sandstone. Fine grained. |
| 11.3 | 4' | White sandstone (same as 11.1). |
| 11.2 | 14'6" | Gray, very fine sandstone and siltstone. Sandstone is subrounded, well sorted. Thinly bedded. Becomes coarser at top. |
| 11.1 | 5' | White sandstone. Hi Fe stain along fractures. Med. grained, subrounded, poor.sorted. Contains qtz-rk frags w/ hi clay matrix. Structureless. |

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