STRATIGRAPHIC DESCRIPTION AND PALEOENVIRONMENTS OF THE BURSUM FORMATION, SOCORRO COUNTY, NEW MEXICO

by

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In Memory of

BROPHY'S KYLE

(July 23, 1982 - March 9, 1990)

Brophy's Kyle: Field Companion and Friend.

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ABSTRACT

Strata within the Bursum Formation just east of Socorro, New Mexico, were studied for stratigraphic description and interpretation of age, paleoenvironment, and provenance. Five complete, composite stratigraphic sections were utilized along with numerous partial sections to achieve this goal.

The Bursum Formation represents a transition from a dominantly marine environment of the underlying Moya Formation, to a dominantly terrestrial environment of the overlying Abo Formation. This transition has been determined to be Wolfcampian in age, based on fusulinid fauna. Strata recording the Bursum environment consist primarily of near-shore deltaic deposits which prograde onto a carbonate producing shelf. In the northern third of the study area, a shallow-water lobate delta system is proposed. Tectonically controlled alluvial-fan debris flow deposits are superimposed on deltaic deposits. In the southern third of the study area, a fan delta system is proposed. Environments recognized from deltaic systems include prodelta, delta-front, delta-plain, channel, and abandonment facies. The middle third of the study area is composed of interfingering lithologies from both deltas.

Cyclic sedimentary sequences typical of Pennsylvanian and Permian strata may also be seen in Bursum Formation sediments. These sequences are caused by: 1) changes in eustatic sea-level; 2) local tectonic events, as

interpreted from a limestone cobble conglomerate (a debris flow deposit related to proximal uplift and erosion); and 3) deltaic progradation and subsidence, as interpreted from deltaic clastics gradationally underlain and overlain by aerially extensive, shallow marine carbonates. Combinations of these three events complicate interpretations made from Bursum sediments on the narrow, marine marginal shelf areas of New Mexico.

Provenance studies of selected clastic units suggest that a continental block provenance is most likely. Lithic grain types further indicate a granitic and gneissic source area. Paleocurrent directional indicators and lithic relationships show two possible source areas. The northern third of the study area is believed to have received clastic input from a low to high gradient system to the north and northwest. This implies a Joyita Hills (Joyita Uplift) source. The southern third of the study area is believed to have received clastic input from a high gradient system to the east and southeast. This may imply a Pedernal Hills (Pedernal Uplift) source to the east or an undocumented local source (small uplifts, to the east,south, or perhaps the west).

At the end of Bursum Formation deposition, the localized Bursum clastic source areas and marine marginal environment were overrun and buried beneath terrestrial clastics representative of the Abo Formation.

INTRODUCTION

In central New Mexico the Pennsylvanian and Permian Systems have been the object of intensive study. The boundary between these systems has typically been described as being gradational, an angular unconformity, or a disconformity. The relatively thin Bursum Formation of central New Mexico is commonly cited as occurring stratigraphically between Pennsylvanian marine carbonates and Permian continental clastics.

Fluctuations in depositional environments during the early Wolfcampian can be seen in the interbedded clastic and carbonate units of the Bursum Formation. Several source areas for clastic input can be postulated due to local and regional tectonism occurring at that time. Sedimentary structures preserved in clastic units and fossils found primarily in carbonate units record the nature of the changing environment of deposition. The Bursum, therefore, holds the answers to many questions concerning the physical environment near the Pennsylvanian-Permian boundary in central New Mexico.

Purpose of Investigation

The objective of this study is a detailed stratigraphic analysis of the Bursum Formation in central New Mexico. This project, although restricted in lateral extent to a north-south trending exposure in central Socorro County, New Mexico, is designed to achieve the following results:

1) determination of age for various horizons in the Bursum Formation using fusulinid fauna;

2) documentation and interpretation of vertical and horizontal variation in paleoenvironments;

3) determination of provenance for clastic bodies and;

4) proposal of an overall depositional model for the study area.

Although this investigation is not expected to radically change the current interpretation for the deposition of the Bursum Formation, its purpose is to look at the Bursum in more detail than previous investigations.

Methods of Investigation

Initial study involved reconaissance from an oil and gas investigation map, OM-121 by Wilpolt and Wanek (1951), at a scale of 1:63,360. Exposed strata of the Bursum Formation within the proposed study area were then explored. Due to complications created by geologic structure, most usable stratigraphic sections of the Bursum are of a composite nature. Five composite stratigraphic sections and numerous partial sections were located and judged suitable for study.

Outcrops of the Bursum Formation in areas of restricted access, on the Sevilleta National Wildlife Refuge and White Sands Missile Range, were studied after permission was granted by the appropriate agencies. The type section of the Bruton Formation (Thompson, 1942) was also visited and studied for stratigraphic comparison with the type Bursum Formation.

Complete composite sections of the Bursum Formation were then measured and described at 5 sites using a Jacob-Staff, Abney Hand Level, Brunton Compass, and tape measure. These sections were measured, utilizing methods outlined by Kottlowski (1965), in areas where structure and exposure permitted the best descriptions. Field descriptions emphasize lithology, color, composition, grain size, primary and secondary structures as well as fossil content.

Field data and hand samples were then analyzed in the lab. Directional current structures were mathematically rotated by means of a computer program to restore original orientations. Fusulinid specimens were sent to D. A. Myers of the U.S.G.S. for identification and age determination. Macrofossils were identified for paleoecological interpretation of the host strata. Ninety oriented thin sections were made from representative as well as critical units. Carbonate rocks were analyzed in thin section for constituent carbonate grains and gross mineralogy to be used in environmental interpretation. Clastic rocks were analyzed in thin section to determine sand mineralogies for provenance studies.

Recorded data are presented on a north-south correlated cross section (Plate 1).

Geographic Location and Geologic Features

The study area lies within a rectangle included in T. 1 S. (projected) to T. 4 S., R. 2 E., Socorro County, New Mexico (Figure 1). Most of this area, with the exception of the Sevilleta National Wildlife Refuge, is on land controlled by the Bureau of Land Management.

The geologic structures in the study area are the product of three Phanerozoic tectonic events: 1) the uplift of the Ancestral Rockies which produced syndepositional deformation; 2) the Laramide Orogeny which produced compressional folding and faulting; and 3) formation of the Rio Grande Rift which produced extensional north-trending normal faults. Syndepositional deformation has been recognized indirectly by the presence of erosional unconformities and conglomeratic channel fill. The compressional folding of the Laramide Orogeny and cross-cutting normal faults of the Rio Grande Rifting event are easily seen within the study area.

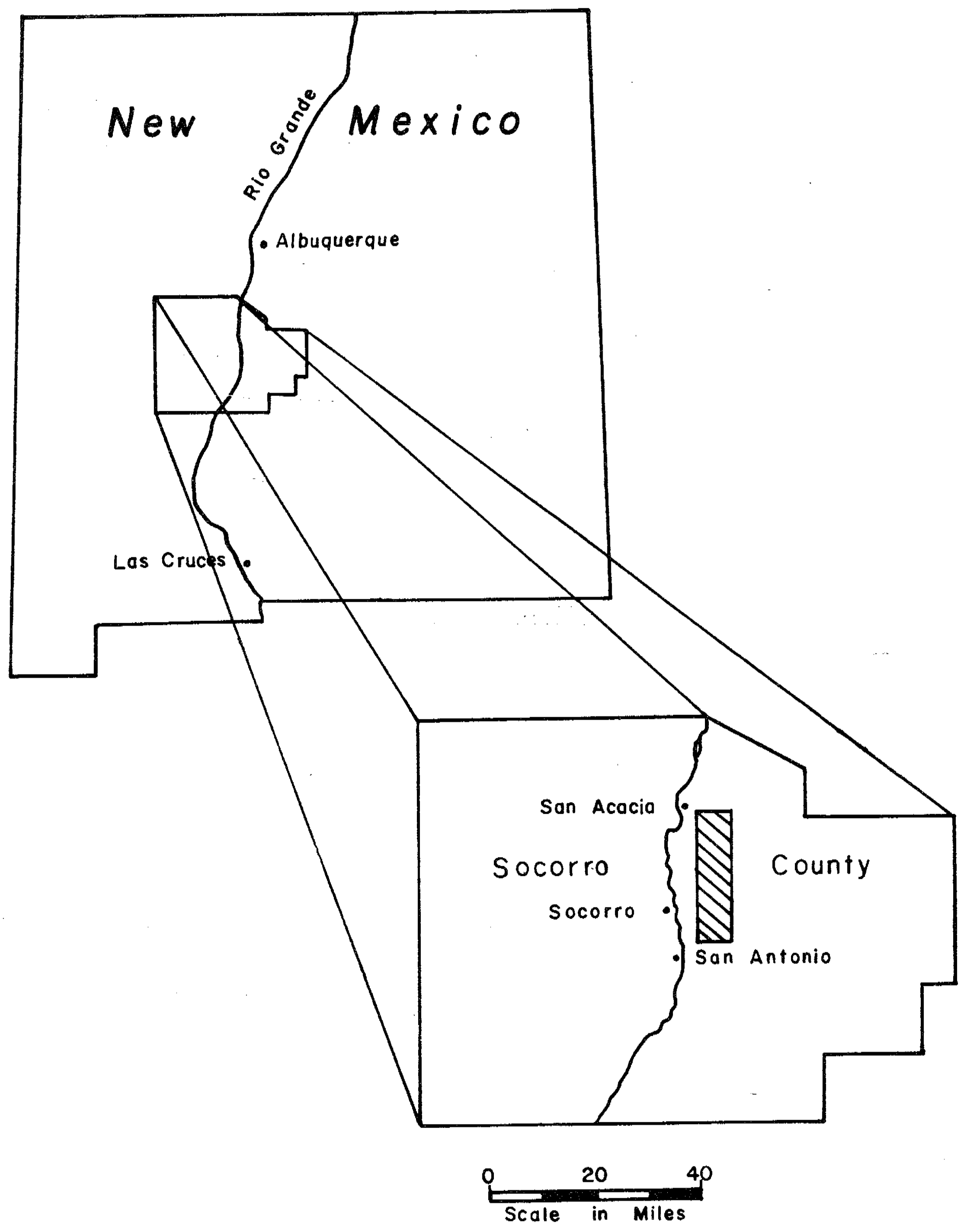


Figure 1: Location map, study area shown by hatchured pattern on Socorro County detail.

Previous Work

The Bursum Formation has been frequently studied over the last 40 years along with other Upper Paleozoic strata of central New Mexico. Within the study area of this report, most previous work has been confined to geologic mapping. Wilpolt and Wanek (1951) mapped the area, and several other geologic maps have been produced for masters theses at New Mexico Institute of Mining and Technology. Theses authors include Rejas (1965), Maulsby (1981), Bauch (1982), and Fagrelius (1982).

A more detailed study by Kottlowski and Stewart (1970) deals with the Bursum Formation in and around the Joyita Hills. The study by Kottlowski and Stewart documents the physical relationships which may well be the key to observed cyclic sedimentation in central New Mexico during the Pennsylvanian and Early Permian. The Joyita Uplift and other local as well as more distant tectonic elements are thought to have contributed to the variety of lithologies seen in the Bursum.

Many previous stratigraphic studies of upper Paleozoic rocks in central New Mexico have dealt with the stratigraphic position and age of lithologies referable to the Bursum Formation. These studies have considered aspects of paleoenvironment, provenance, and depositional modeling for the Bursum, but have not studied these relationships in detail within the study area of this report.

STRATIGRAPHY

Introduction

The name Bursum Formation was used by Wilpolt _et_ _al_. (1946) for strata exposed just west of the Bursum triangulation point in SE 1/4, section 1, T. 6 S., R. 4 E., Socorro County, New Mexico. At the type locality the Bursum is 250 feet thick and is described as consisting of thick sequences of dark purplish-red and green shales separated by thinner beds of arkose, arkosic conglomerate, and gray limestone (Wilpolt _et_ _al_., 1946).

The legitimacy of the Bursum Formation as a mappable unit outside central New Mexico is the subject of some discussion. The Bursum is laterally and vertically transitional with underlying carbonates and overlying clastics. The result is a situation where thinning of the Bursum may make mapping as a distinctive lithologic unit difficult or impossible.

Within the study area covered by this paper the Bursum Formation is easily identified and mappable and thus qualifies for formational rank. Furthermore, Kottlowski and Stewart (1970, p. 23) state that: "In the Los Pinos Mountains and other Permian outcrops to the south and southeast the Bursum is a well defined and mappable unit.".

The diverse lithologies combined with lateral variations in thickness and age of the Bursum Formation have given rise to several different names for lateral equivalents. A summary of the Pennsylvanian-Permian lithostratigraphic nomenclature as used by other authors and this paper is shown in Figure 2.

Contact Relationships

Contact relationships of the Bursum Formation seem to be as variable as the Bursum lithology. In the interest of following previously established stratigraphic boundaries, the contact definitions employed in the literature were used and proved adequate for this study.

The basal unit of the Bursum Formation overlying the Arkosic Limestone Member of the Madera Formation (Moya Formation of this report; see Figure 2) was described by Wilpolt *et al*. (1946) in the Los Pinos Mountains as consisting of a thin, rubbly, nodular, purplish-gray limestone. This limestone was believed to be locally derived from the underlying unit. Other authors have defined the lower contact of the Bursum as gradational in the Manzano Mountains (Myers, 1982, p. 236), a disconformity in the Sacramento Mountains (Otte, 1959, p. 22), or an angular unconformity in the Joyita Hills (Kottlowski and Stewart, 1970, p. 23).

In the area covered by this study the lower contact of the Bursum Formation is easily recognized. The contact is placed at the lithologic transition from massive, gray, fossiliferous marine carbonates of the Moya Formation, to purplish-red claystones of the Bursum. This transition

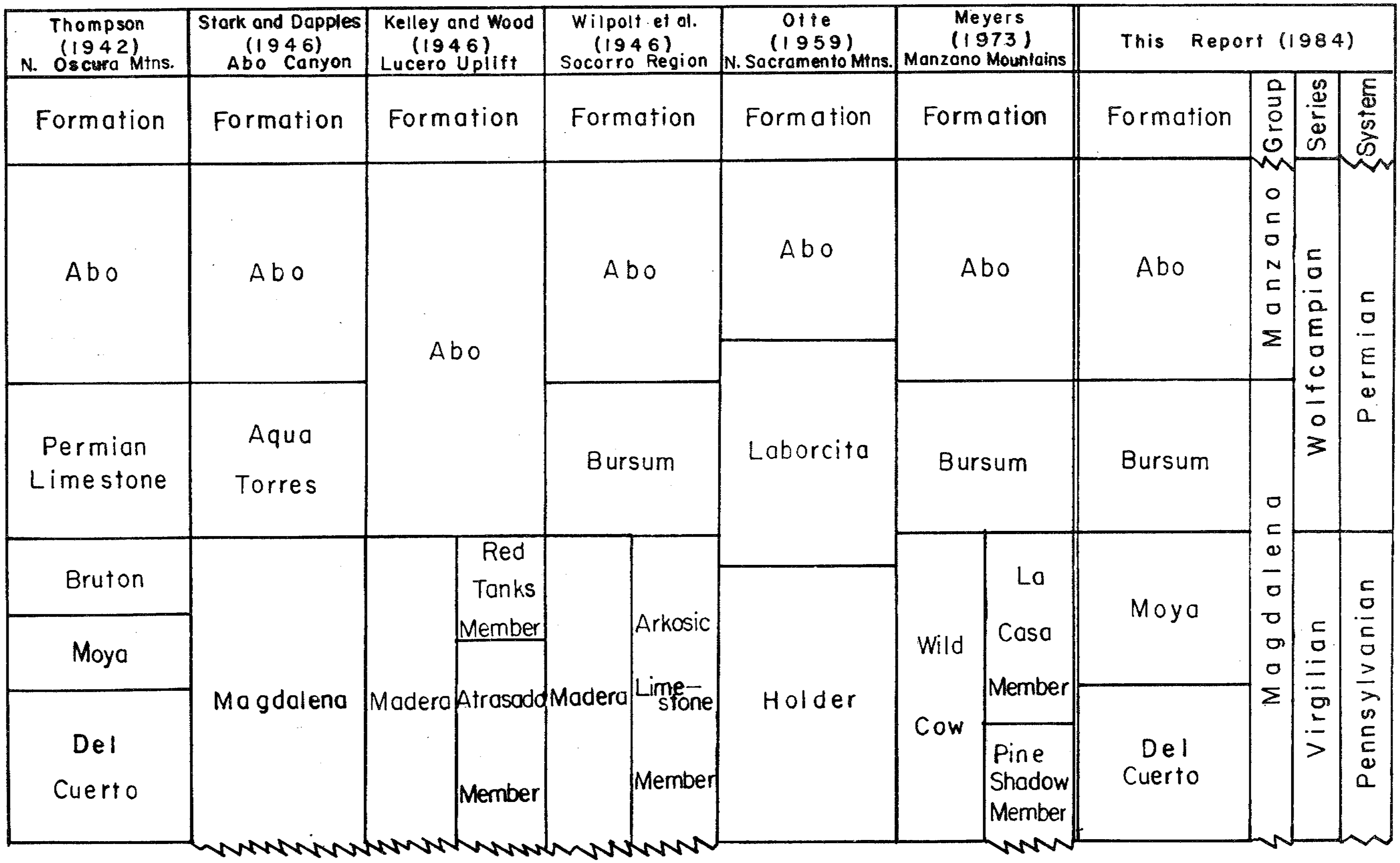


Figure 2: Summary of nomenclature for Virgilian-Wolfcampian strata in central New Mexico.

contains a zone of rubbly, nodular, shaly, purplish-gray limestone of varying thickness. This zone seems to have resulted from the partial mixing of underlying unconsolidated carbonate mud with overlying clay and silt particles and not to an erosional reworking of underlying lithified carbonates.

Limestone conglomerate and sand, which fill channels eroded into the underlying Moya Formation, also mark the contact locally. This type of erosional contact is not widespread and can be traced only a short distance laterally.

Several thin tongues of Bursum-like purplish to greenish shales were noted below the contact at a few locations. These tongues are considered to be part of the underlying Moya Formation, but do illustrate the transitional nature of the Bursum Formation lower contact at these locations.

The upper contact of the Bursum Formation with the Abo Formation is difficult to identify and often covered with talus. Lee (1909) defined the Abo as usually being conglomeratic at its base. Needham and Bates (1943, p. 1957) implied that the lower contact of the Abo should be positioned above the highest occurring limestone or marine fossil bearing unit.

For this study, the contact of the Bursum Formation with the Abo Formation was placed at the top of the highest marine fossil bearing carbonate unit of the Bursum. Where a gray claystone with micritic nodules occurs above this horizon, the claystone was also included as part of the Bursum. This practice is adopted due to the gray coloration, micritic nodules, and possible marine fossil content of this claystone which more closely resembles Bursum lithologies. It is important to note that the micritic nodules mentioned here are distinctly different from the calcisol nodules which occur in the overlying Abo Formation.

Although the upper contact of the Bursum Formation is generally gradational, at some localities diastemic breaks and erosional channels also mark this contact. Locally a thick sequence of arkosic, granule to cobble conglomerate fills broad sheet-like channels in the upper shales of the Bursum. This conglomerate is considered to be the lower member of the Abo Formation by Cappa (1975, p. 19) or "granite wash" by others elsewhere. This premise is adopted, but it is also noted that equivalents of this conglomerate are likely to intertongue with Bursum lithologies within the study area. Differences in thickness of the Bursum within the study area are due in part to the difficulty in selecting the upper contact.

For this report the Bursum Formation will be considered to lie conformably above the Moya Formation and conformably beneath the Abo Formation unless otherwise specified.

Age Relationships

The type Bursum Formation, based on fusulinid fauna, has been considered to be Wolfcampian in age (Wilpolt et al. 1946). Thompson (1954) later showed that the basal type Bursum was Virgilian in age. Other evidence, from the literature, also suggests that the Bursum Formation of central New Mexico may locally span the time boundary between the Pennsylvanian and Permian Systems.

Fusulinid samples from this study identified by D. A. Myers yield Wolfcampian ages. These fusulinids include Schwagerina pinosensis, Triticites aff. T. creekensis, Triticites cf. Triticites directus, and Leptotriticites sp. (Myers, personal comm., 1984). The fusulinid Triticites directus was collected from the lower contact of the Bursum Formation. All other fusulinids, with the exception of Schwagerina pinosensis, were collected less than 30 feet above the lower contact (see Plate 1). These fusulinids, which are below a widely occurring erosional unconformity, indicate the age of the Bursum in the study area is younger than the Pennsylvanian-Permian boundary.

Stratigraphic Description

The Bursum Formation is herein divided into three informal zones which are recognizable within the study area. These zones in ascending stratigraphic order are: 1) the lower clastic zone; 2) the middle carbonate zone; and 3) the upper mixed zone (see plate 1). Due to extreme lateral variation in lithic facies the Bursum is grouped into two generalized stratigraphic sequences for description. These generalized stratigraphic sequences will approximate the northern third (sites 1 and 2) and the southern third (site 5) of the study area. The middle third of the study area (sites 3 and 4) contains the interfingering lithologies of the northern and southern sections. The middle third of the study area will not be described in detail. The reader is referred to Figure 32, page 88 of this text, for a graphic interpretation of the interrelationship between study sites.

Appendicies A through H contain all data collected and compiled for this study. The reader is referred to Plate 1 for the following descriptions.

Northern Section

In the northern third of the study area the Moya Formation lies comformably beneath the Bursum Formation. The upper units of the Moya Formation are massive, gray, fossiliferous, cliff-forming carbonates. These carbonates are composed of micritic mudstones to grain supported biosparites. As the contact with the Bursum is approached the Moya becomes thin-bedded to nodular and contains fine-grained clastic impurities.

The contact between the Moya Formation and the Bursum Formation is conformable and contains a unit of mixed lithologies. Fusulinids found in carbonate nodules from this contact are identified as a Permian variety.

Lower Clastic Zone

Above the Moya Formation-Bursum Formation contact the lower clastic zone is dominated by a series of non-fossiliferous, red to green clastic units. A red claystone unit immediately above the contact is very thin-bedded to laminated or structureless. This claystone grades upward into reddish, micaceous siltstones and sandstones. Typically planar-bedded, the siltstones and sandstones locally contain trough-shaped sets of crossbeds which fill erosive channels (the terms "trough- and tabular-shaped crossbeds" are also used herein as a shortened form of "trough- and tabular-shaped sets of crossbeds").

Above the siltstones and sandstones the strata grade upward into structureless claystone that changes color from red to gray. As the strata become gray they become more calcareous and often contain small micritic nodules. Upward the strata become increasingly calcareous until they grade into a thin-bedded, nodular limestone. This limestone is richly fossiliferous and locally contains an abundant fusulinid fauna (Figure 3).

Above this fusulinid limestone the strata grade into a gray, calcareous claystone. This claystone contains micritic nodules and is very thin-bedded or structureless. Upward the color of this claystone changes from gray to purple to red and is accompanied by a decrease in micritic nodule content.

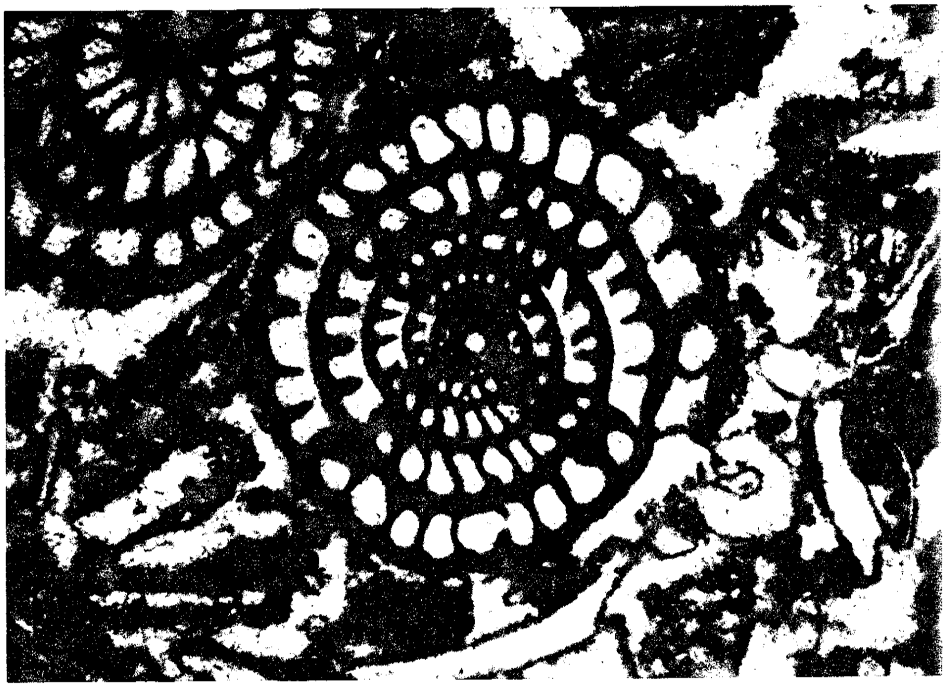


Figure 3: Photomicrograph of <u>Triticites creekensis</u>, in plane-polarized light, from the lower clastic zone (unit 5 at site 2). (Bar for scale is 1.0 millimeter long.)

Figure 4: Limestone cobble conglomerate from the lower clastic zone (unit 7 at site 2).

At this level the stratigraphic sequence is interrupted by an erosional unconformity. This unconformity is locally associated with channels, up to 15 feet in thickness, eroded into the upper beds of the underlying Moya Formation (Kottlowski and Stewart, 1970). Field evidence shows the erosive nature of these channels decreases eastward and southward.

The channels are filled with a locally derived limestone conglomerate (Figure 4). This conglomerate is composed of poorly sorted, subrounded, subelongate, pebble to boulder sized clasts of fossiliferous limestone in random orientations. The matrix of the conglomerate unit consists of sand, silt, and clay sized clasts of quartz and potassium feldspar with a calcareous cement. The maximum clast size, several feet in diameter (Kottlowski and Stewart, 1970), corresponds with maximum bed thickness.

Distally, to the south and east, the conglomerate unit becomes thin- to medium-bedded and may contain several stacked beds. These beds are often separated by thin interbeds of coarse-grained sandstone with low angle crossbeds or parallel laminations.

Above the conglomerate is a sequence of interfingering lithologies which represent the upper beds of the lower clastic zone. These lithologies consist of: 1) a basal, discontinuous sheet-like body of light brown, thick-bedded, fine- to coarse-grained, sandstone with angular, well sorted clasts of quartz and potassium feldspar. This sheet-like sandstone also contains fossilized plant remains, structureless beds, laminations, trough- and tabular-shaped sets of crossbeds, and fining upward sequences; 2) a red, fining upward sequence of planar-bedded, cross-laminated, color mottled, arkosic sandstone, siltstone, and claystone; or 3) a green to gray, thin-bedded to laminated, calcareous, arkosic sandstone to claystone which contains desiccation cracks (Figure 5), coaly lenses (Figure 6), plant leaves (Figure 7), root casts, septarian nodules, and algal encrusted trees (Figures 8 and 9) in growth position. The transition from underlying conglomerate to the overlying stratum is usually sharp. Some reworking or mixing of lithologies is seen however, when the overlying stratum is a crossbedded sandstone.

Middle Carbonate Zone

Above the lower clastic zone lies the middle carbonate zone. The contact between these two zones is gradational and usually placed at a horizon above which the strata are considered to be dominantly carbonate in composition. The lower units of this zone are composed of gray, abundantly fossiliferous, thin-bedded limestones or purple-gray, sparsely fossiliferous, nodular limestones.

Where the limestones are abundantly fossiliferous they contain a diverse fauna consisting of rugose corals, digitate and fenestrate bryozoans (Figure 10), and whole articulated molluscs and brachiopods. Other faunal forms

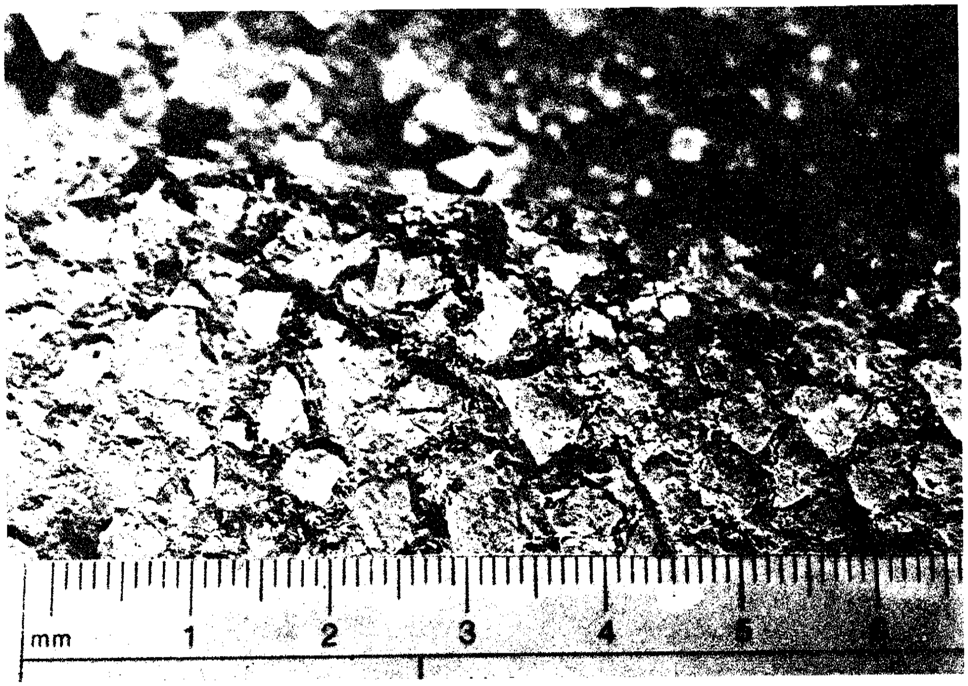


Figure 5: Mudcracks from the lower clastic zone. Located NW 1/4, SW 1/4, Section 14, T. 2 S., R. 2 E., Socorro County, New Mexico.

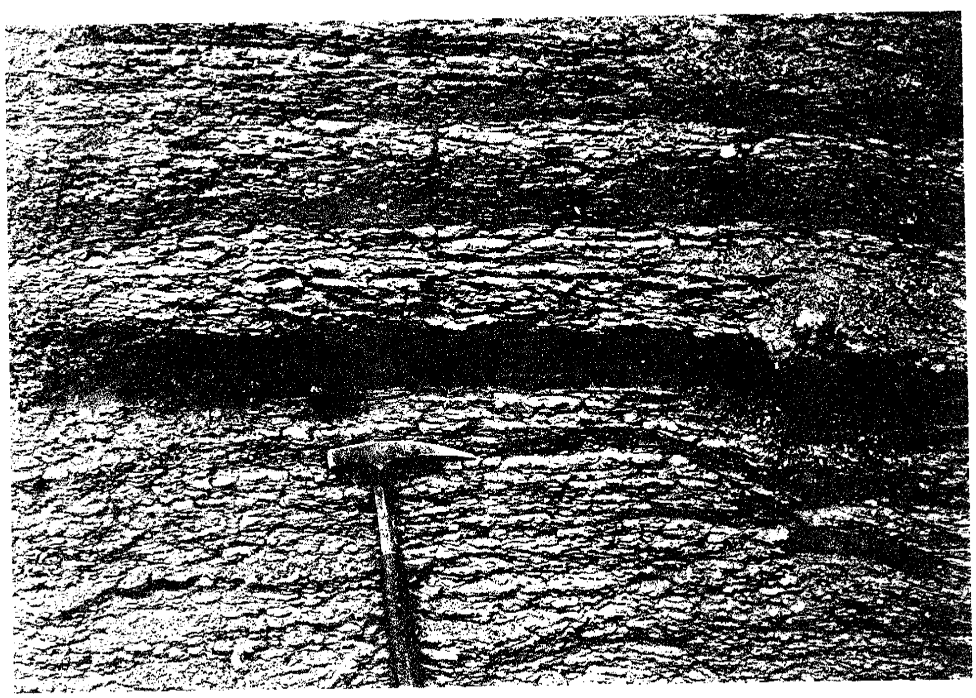
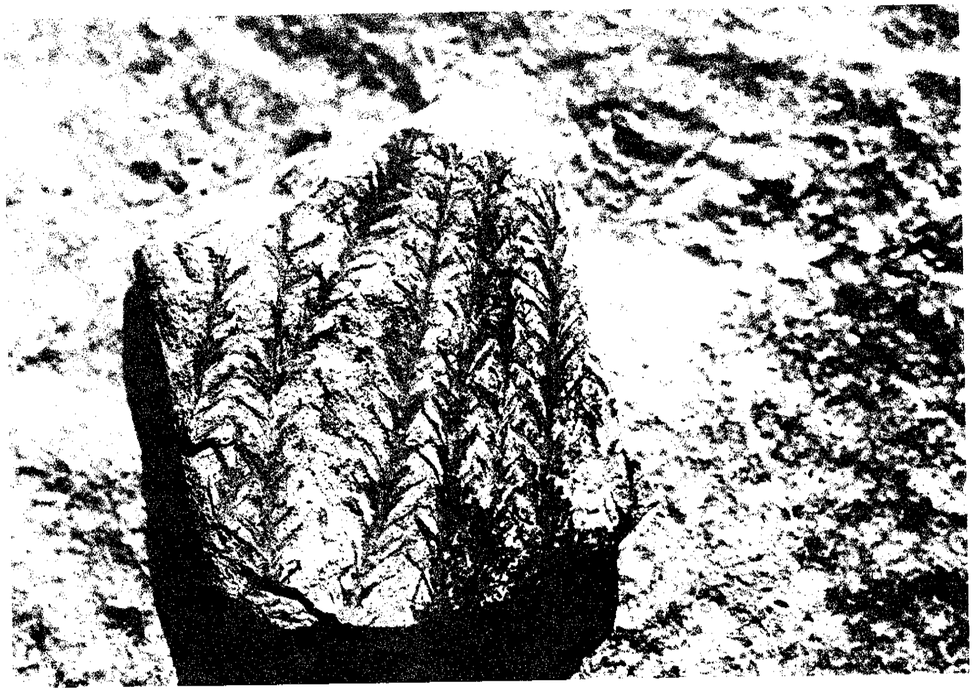


Figure 6: Coaly lens from the lower clastic zone. Located NE 1/4, NW 1/4, Section 9, T. 2 S., R. 2 E., Socorro County, New Mexico.

A.



B.

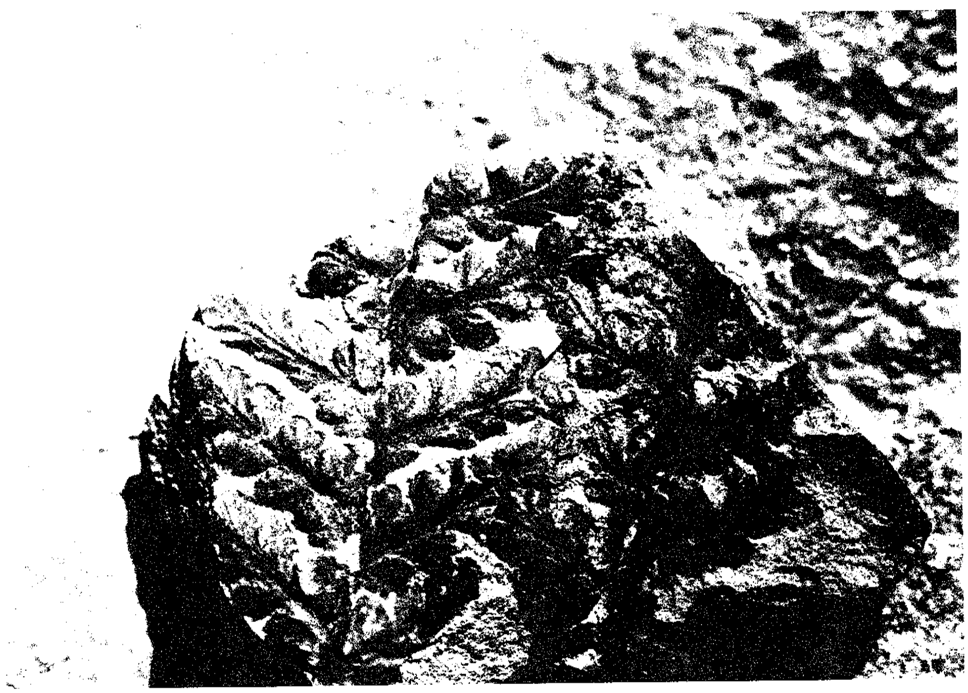


Figure 7: Leaf impressions from the lower clastic zone (unit 6 at site 3).

A. Walchia piniformis.
B. Ovopteris communis.
(Both photos approximately life size.)

Figure 8: Algal encrusted fossil tree in growth position from the lower clastic zone. Located SE 1/4, SE 1/4, Section 9, T. 2 S., R. 2 E., Socorro County, New Mexico.

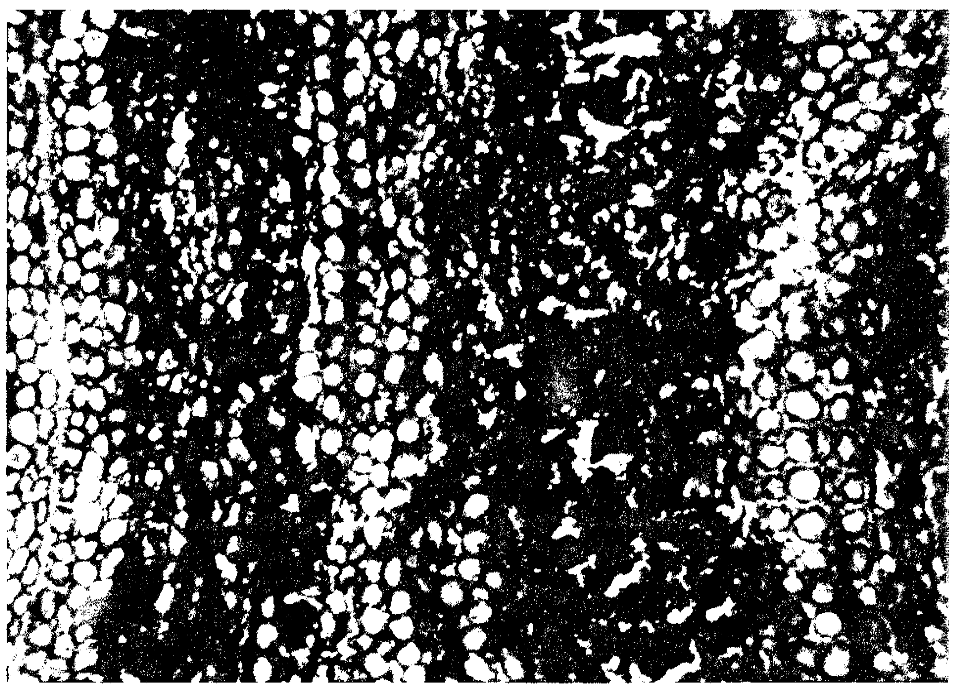


Figure 9: Photomicrograph of a vertical section through algal encrusted fossil tree from the lower clastic zone (plane-polarized light). Note cellular nature of preserved tree tissue. (Bar for scale is 0.5 millimeters long.)

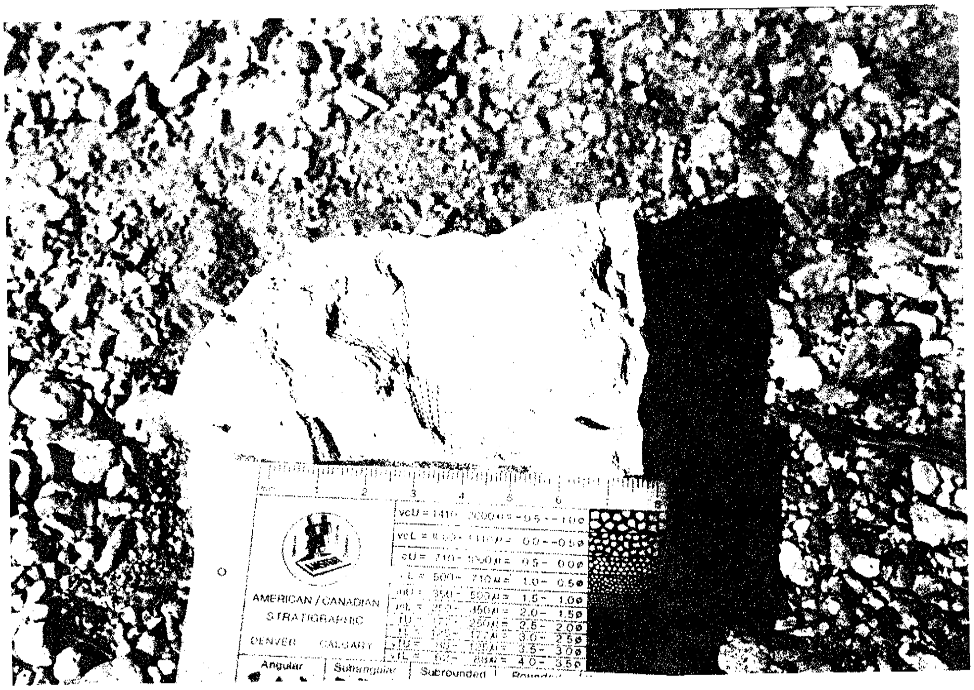


Figure 10: Fenestrate bryozoan from the middle carbonate zone (unit 15 at site 2).

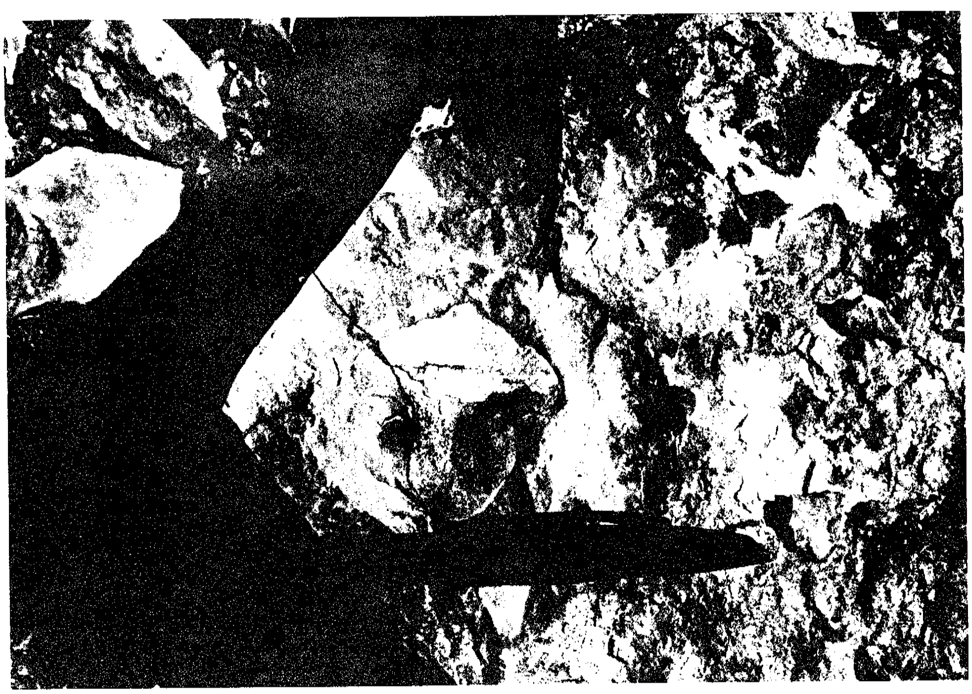


Figure 11: Shark tooth (Janassa ?) from the middle carbonate zone (unit 9 at site 1).

include pelmatozoan, echinoid, trilobite, foram, ostracod, and vertebrate (Figure 11) remains.

Where the limestones are sparsely fossiliferous, they are nodular and typical of nodular limestones throughout the Bursum Formation. Stark and Dapples (1946, p. 1154) described these nodular limestones in the Los Pinos Mountains:

> Above...are several layers, each approximately 1-2 feet in thickness, of gray to purplish-gray nodular limestones separated by equally thin layers of shale. The nodular limestones consist of rudely rounded or ellipsoidal calcareous nodules cemented in a calcareous but slightly more argillaceous matrix. The matrix is predominantly gray but has in places purplish streaks which tend to give the entire bed a purplish cast, particularly on the weathered surface. Locally the matrix contains much shale, and the nodular limestone layers are thin, but elsewhere, such as along the northern edges of the fault blocks at the south end of the range, the shaly part diminishes and the nodular limestone thickens to 5 feet.
>
> The nodules are for the most part approximately 2-3 inches in diameter, but they are not uncommonly as large as 5 inches. Their surfaces are irregular and pitted. The internal structure is dense or finely crystalline and shows no suggestion of concretionary or algal structures. Nodular limestone layers in approximately the same stratigraphic position have been observed in exposures along the highway east of Mt. Paloma, also at the south end of the range, and it is presumed, therefore, that this is a continuous stratigraphic marker....

Jasperoid nodules and very thin, irregular jasper beds are common in the nodular limestone. Selective replacement of fossils by jasper is also common in the fossiliferous limestones.

Above these lowermost beds of the middle carbonate zone the stratigraphic sequence becomes laterally variable. A structureless claystone overlies the lowermost limestone. This claystone changes color upward from red to purple to gray.

Southward the claystone interfingers with beds of dolomite, dolomitic limestone (Figure 12), and massively bedded, sparsely fossiliferous, micritic limestone. Associated with the beds of dolomite and micritic limestone are algal laminations and algal rip-up clasts (Figure 13). Above this is a thick sequence of gray, thin-bedded, sparsely fossiliferous limestones with very thin siderite interbeds.

At this level the stratigraphic sequence throughout the northern third of the study area becomes more uniform. The strata consist of purple-gray, medium- to thin-bedded, fossiliferous, shaly to micritic limestones. Numerous vertical and horizontal burrows can be found in these limestones. Fossils found in these limestones include all those found in the lowermost beds of the middle carbonate zone plus many additional species. Many fossils in these limestones are articulated and most are replaced by jasper (Figure 14).

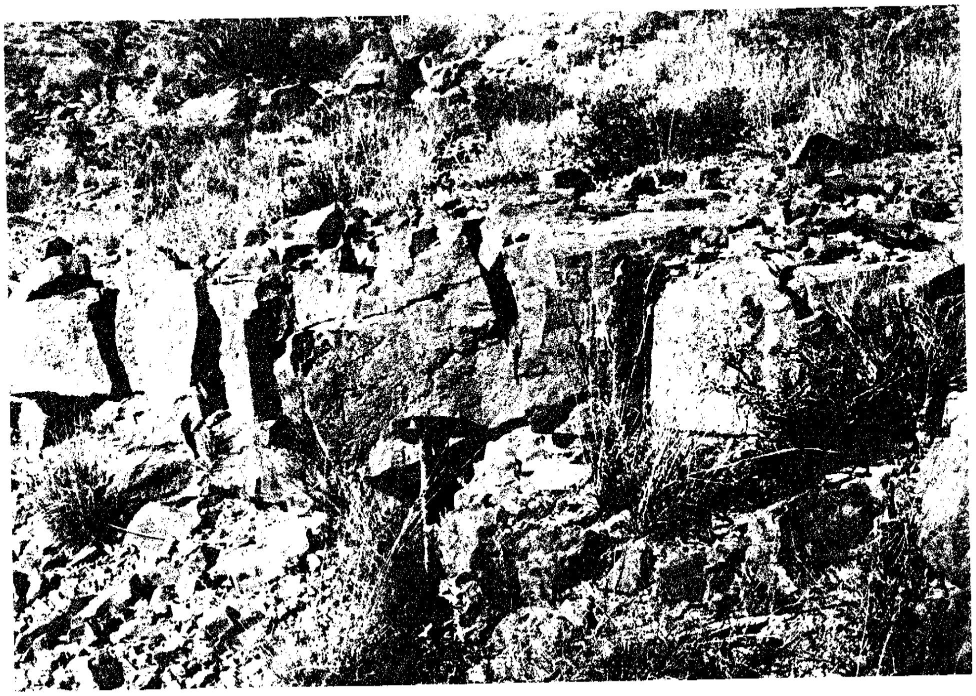


Figure 12: Orange weathering dolomite-dolomitic limestone bed from the middle carbonate zone (unit 11 at site 2).

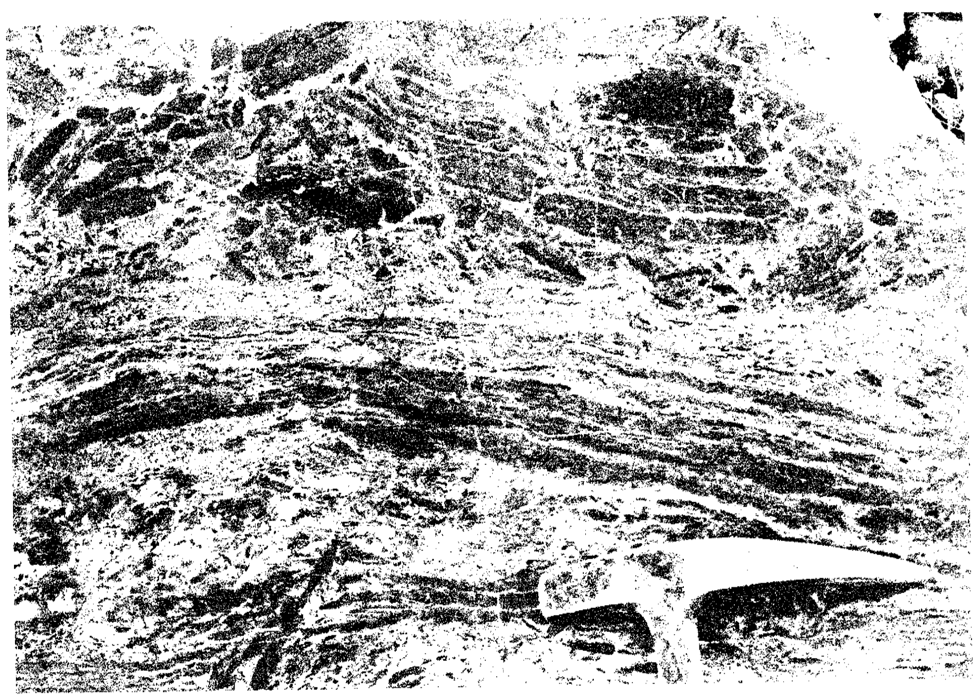
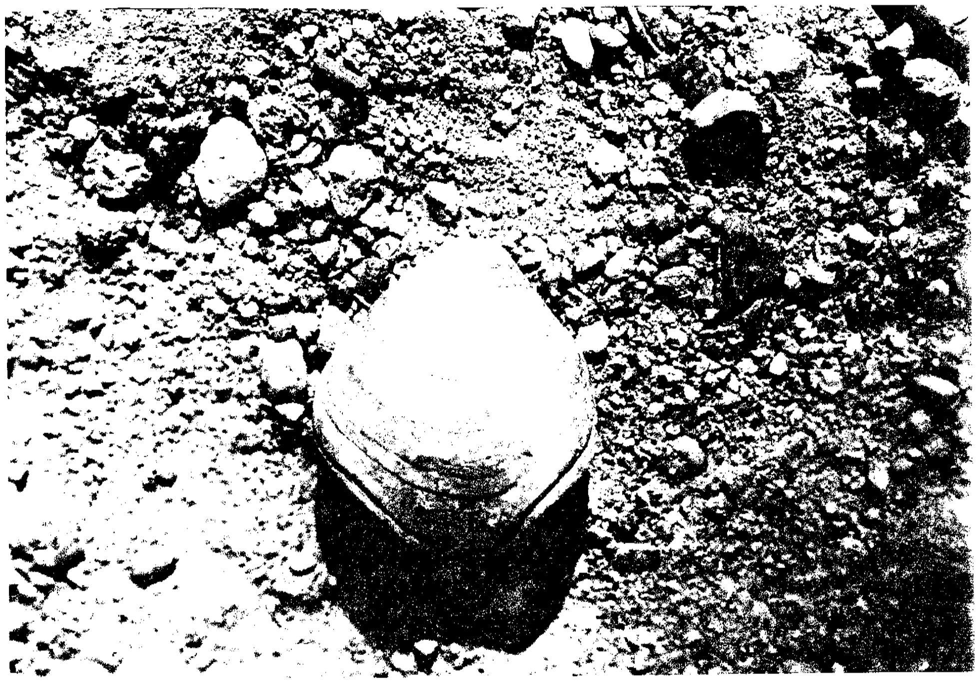


Figure 13: Algal laminations and rip-up clasts from the middle carbonate zone (unit 13 at site 2).

A.



B.

Figure 14: Jasper replaced fossils from the middle carbonate zone (unit 9 at site 1).

A. <u>Composita</u> <u>ovata</u>.
B. Crinoid stem (with millimeter scale).
(Both photos are same scale.)

Above this fossiliferous limestone is a sequence of gray to purple-gray, thin-bedded, sparsely fossiliferous limestones, nodular limestones (Figure 15), and non-fossiliferous, gray to purple claystones. These beds represent the uppermost strata of the middle carbonate zone and are often erosionally truncated.

Shallow channels associated with the erosional truncation of the uppermost beds of the middle carbonate zone are filled with limestone pebble to cobble conglomerate. This conglomerate is similar to the conglomerate described in the lower clastic zone. Oncolitic growths (Figure 16) on limestone clasts are seen locally within this conglomerate. Where erosional truncation is not pronounced, granule sized clasts of well rounded, well sorted limestone mark the contact between the middle carbonate zone and the upper mixed zone.

Upper Mixed Zone

The upper mixed zone is laterally and vertically variable with respect to carbonate and clastic lithology. The lower units of this zone are composed of claystones, siltstones, and sandstones with a gray, purple, or red coloration. These lower units are thinly bedded to structureless and may contain terrigenous plant debris. A general coarsening upward of grain size is noted.

Above these lower units are gray, thin-bedded to very thinly bedded limestones with interbedded gray claystones.

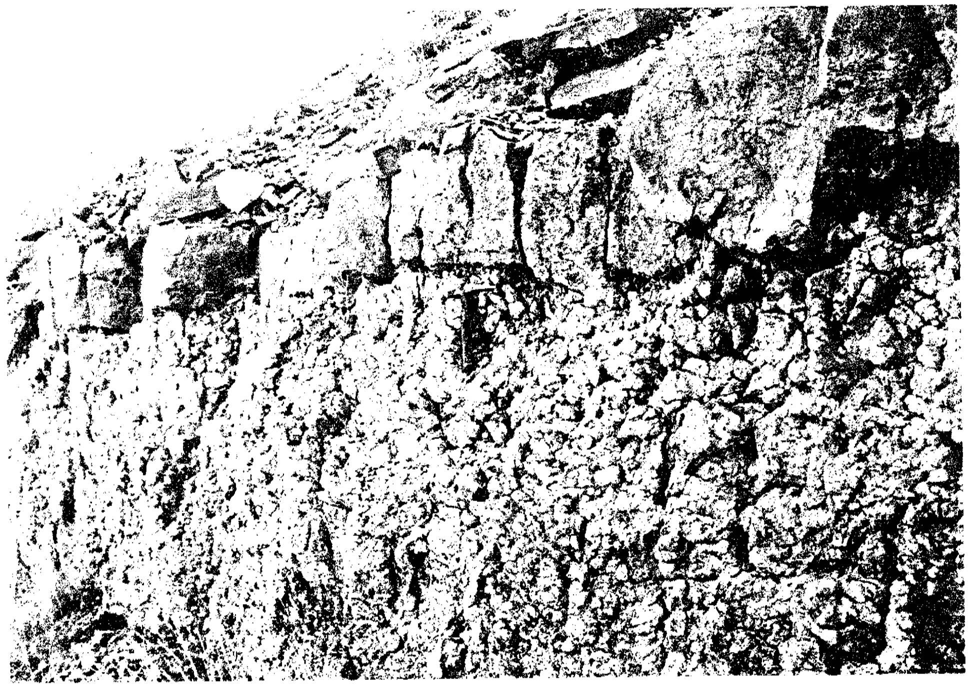


Figure 15: Nodular limestone from the middle carbonate zone (unit 20 at site 2).

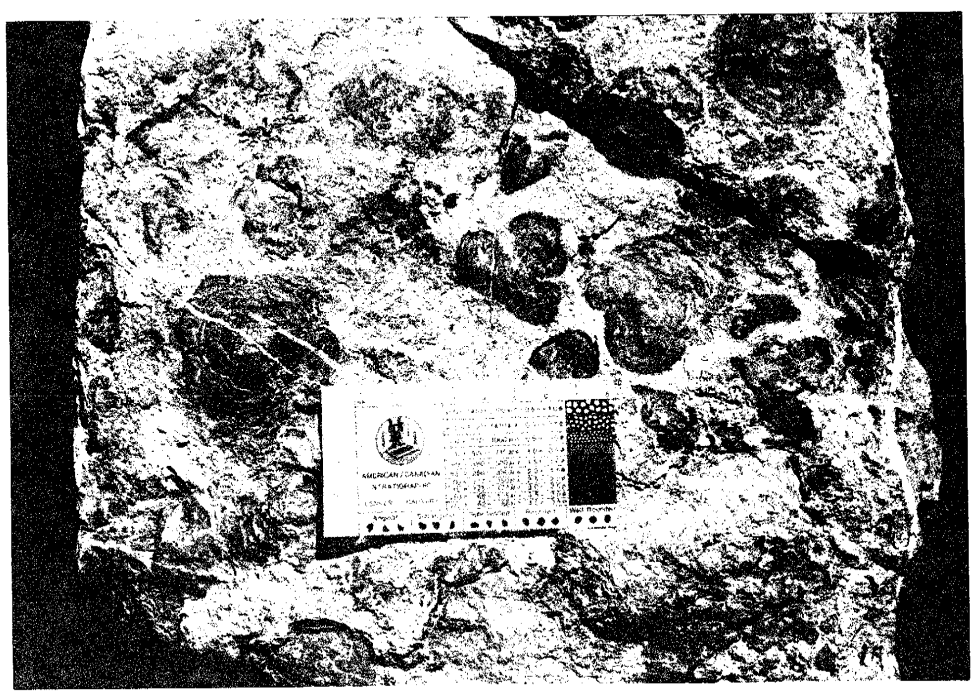


Figure 16: Oncolites from the upper contact of the middle carbonate zone (unit 12 at site 1).

The limestones are fossiliferous and may contain algal encrusted mollusc shells. The claystones are also fossiliferous and contain abundant mollusc remains, particularly nuculid pelecypods.

Above these mollusc bearing units are several units of siltstone and fine-grained sandstone. These strata are planar-bedded, reddish in color, and show a variety of sedimentary and biogenic structures. Structures include disk-shaped slump features, load casts, parting lineation, horizontal trails and traces, vertical burrows, and ripple marks of the oscillation, linguloid, and interference varieties. Lateral variations of the clastic units include calcareous sandstones which display convolute and oversteepened crossbedding, trough and tabular-shaped sets of crossbeds, and erosional channels filled with crossbedded calcareous sands and carbonate rip-up clasts.

Southward this sequence is capped by a light brown, arkosic sandstone which contains well sorted, subrounded, coarse-grained sand clasts. This sandstone unit contains much fossil plant debris and both trough- and tabular-shaped sets of crossbeds.

Above these sandstone units is a sequence of gray, thin-bedded, fossiliferous carbonates interbedded with gray or purple claystones and clay-shales. The carbonates exhibit color mottling and siderite locally. The claystones and clay-shales are very thinly bedded or structureless and contain limy zones with vertebrate remains and an abundant molluscan fauna. The molluscan fauna consists of bellerophontid gastropods and nuculid pelecypods.

In the northern section of the study area the Bursum Formation-Abo Formation contact is considered conformable and is placed at the stratigraphically highest occurring limestone. This limestone locally contains reworked limestone pebbles and many vertebrate remains.

Southern Section

In the southern third of the field area the Moya Formation lies conformably beneath the Bursum Formation. The description of the Moya here is essentially the same as the northern section with one exception. This exception is the presence of Bursum-like lithologies in the upper units of the Moya. Examples of Bursum-like lithologies in the Moya include red and green siltstone lenses at site 4, sandstone bodies at Cerros de Amado, and limestone and quartz cobble conglomerates at site 5.

The Moya Formation-Bursum Formation contact at this location is identical to the contact described in the northern section.

Lower Clastic Zone

Above the Moya Formation-Bursum Formation contact the lower clastic zone resembles that of the northern section. Red colored, non-fossiliferous, thin-bedded to laminated claystones grade upward into siltstones and sandstones.

The siltstones and sandstones are planar-bedded but locally contain low angle trough-shaped crossbeds.

Above the siltstones and sandstones the strata grade upward to a red claystone. This claystone in turn grades upward into a gray, calcareous claystone with micritic nodules. The micritic nodule content decreases upward as the claystone changes color from gray to purple to red and becomes interbedded with thin lenses of arkosic sandstone.

Above this is a thick sequence of gray, purple, or red claystone units with interbedded red arkosic clastic units. The claystones are poorly exposed but are believed to be thick- to thin-bedded and structureless. The arkosic clastic units are composed of poorly sorted, rounded to angular, sand to cobble sized clasts of quartz, potassium feldspar, and granite (Figures 17 and 18). Maximum clast size and bed thickness in clastic units increases upward. Bed geometry of clastic units is sheet-like with pinching and swelling observed laterally. Locally, small mudcracks are observed at the contact between fine-grained (clay and silt) units and underlying coarse-grained sand and pebble units. Bedding structures in the coarse-grained units are poorly preserved, but trough- and tabular-shaped sets of crossbeds, gravel lags and bars, and both fining and coarsening upward sequences are observed.

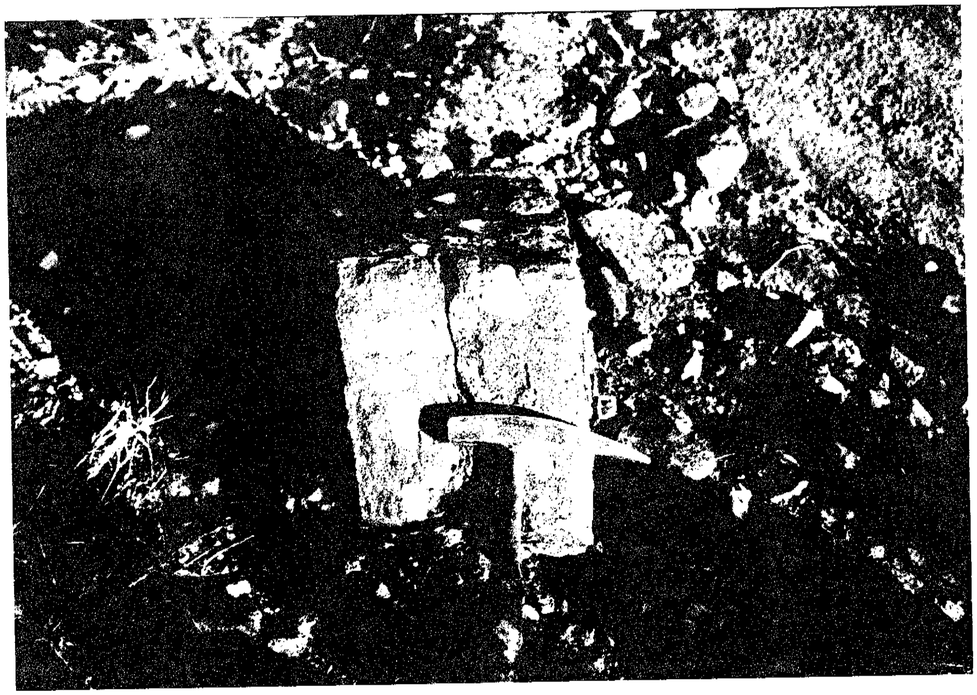


Figure 17: Pebble to cobble-sized clasts of rounded quartz from the lower clastic zone (unit 8 at site 5).

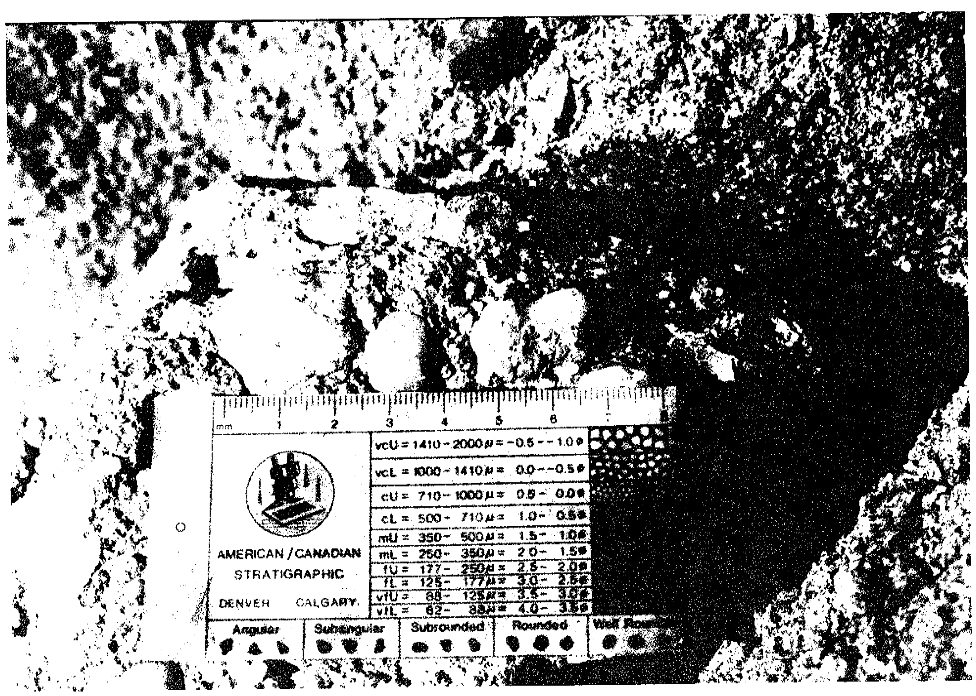


Figure 18: Pebble to cobble-sized quartz, feldspar, and granite clasts from the lower clastic zone (unit 8 at site 5).

Middle Carbonate Zone

Conformably above the lower clastic zone lies the middle carbonate zone. The contact between the lower clastic zone and the middle carbonate zone is placed at a horizon where the lithology changes from clastic to carbonate. The basal unit of this zone is a brown-gray, fossiliferous, sandy limestone. This limestone becomes increasingly sandy upward until its upper surface is a brown, calcareous sandstone.

Above this sandy limestone is a gray, fossiliferous, nodular limestone. This limestone locally contains numerous fusulinids and grades upward into a gray structureless claystone with micritic nodules.

The Bursum Formation-Abo Formation contact is conformable and placed just above the gray claystone. Above this contact is a clastic sequence containing interbedded arkosic units (with sand to cobble sized clasts) and red claystones. Northward, these arkosic clastic units interfinger with Bursum carbonates and form the upper mixed zone lithologies of sites 3 and 4.

Upper Mixed Zone

The upper mixed zone is either not present or not recognized in the southern section of the study area. It should be noted that the middle third of the study area, sites 3 and 4, contain upper mixed zone lithologies which thin southward.

In the southern section of the study area the Bursum Formation-Abo Formation contact is considered conformable, but is locally erosional. This contact is placed at the stratigraphically highest occurring marine fossil-bearing limestone or gray shale. Abo Formation clastics locally fill channels eroded into the Bursum Formation.

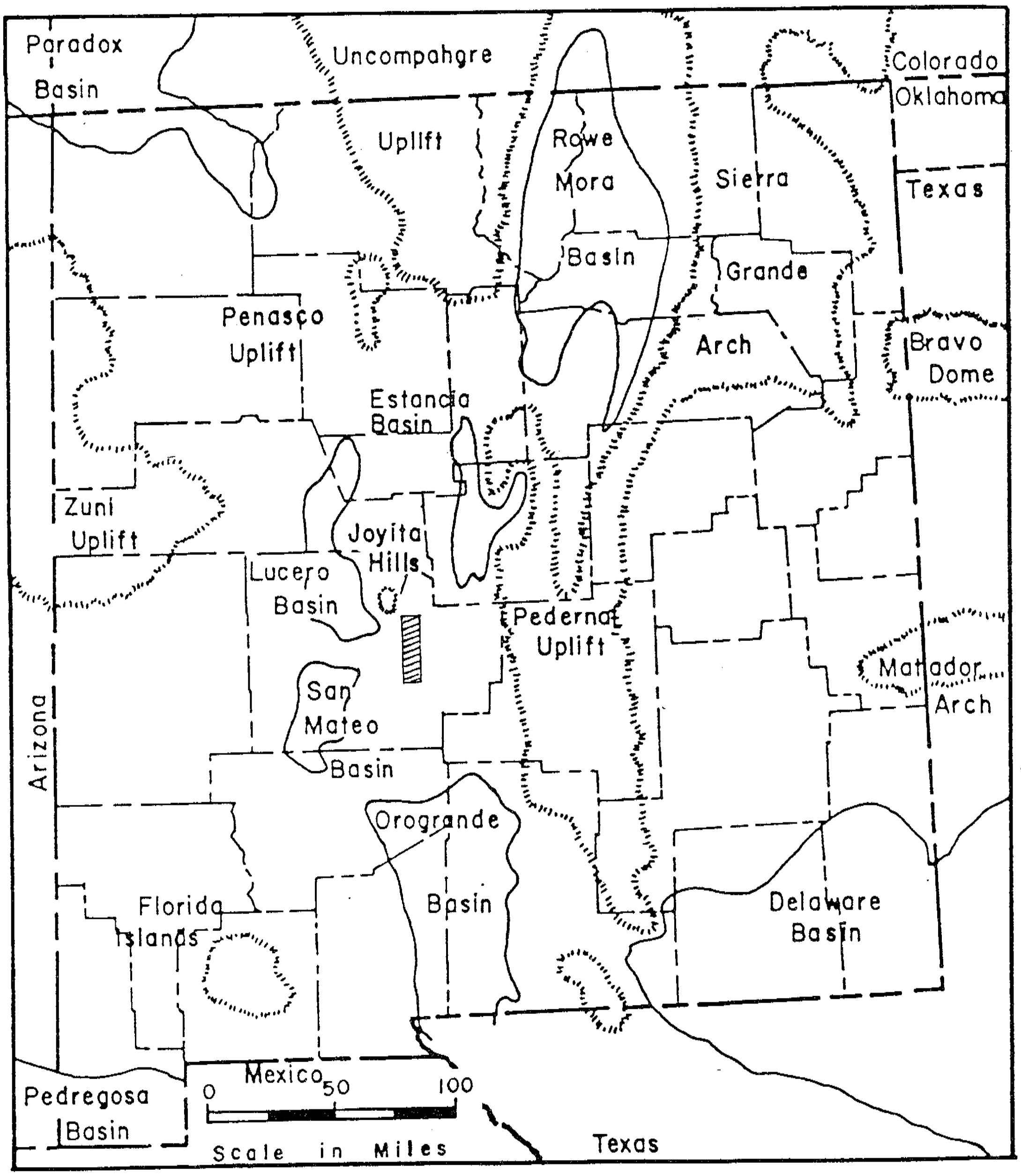


Figure 30: Late Pennsylvanian paleogeographic map of New Mexico (after Kottlowski, 1960). Study area is shown by hatchured pattern.

due to distance involved or lack of exposure during Pennsylvanian and Permian times (Figure 30).

A Joyita Hills (Joyita Uplift) source area for clastic units in the northern portion of the study area is easy to document using lithic relationships (Plate 1), paleocurrent structures (Figures 33-39, in Appendix F), and grain mineralogies (Appendix B). A small percentage of clastics may have been released from eroded Pennsylvanian arkosic limestone units, but are also considered to be locally derived.

Coarse-grained clastics of the lower Abo Formation in the Cerros de Amado area (Cappa, 1975) are considered stratigraphically and lithologically equivalent to certain clastic units within the Bursum Formation. Cappa (1975) concluded, based on mineralogy, that the granitic and gneissic Joyita Hills (Joyita Uplift) was the most probable source area for these clastics. Coarse-sand to cobble-sized arkosic clasts of the Bursum Formation in the southern portion of the study area could have been derived from the Joyita Hills (Joyita Uplift), based on mineralogy alone, but another source is more strongly indicated.

Data which points to a southerly source area and precludes a Joyita Hills (Joyita Uplift) source for clastics in the southern third of the field area includes: 1) east-west oriented erosional channels filled with limestone, quartz, and feldspar cobbles (Figure 31) found in the Moya Formation at site 5; 2) other similar channels of sandstone,

Figure 31: Channel filled with limestone, quartz, and feldspar conglomerate in Moya Formation at site 5.

siltstone, and claystone found in the Moya with increasing frequency southward; 3) juxtaposed, diagnostic lithologies at site 4 (Plate 1); 4) marked increase in maximum and average clastic grain size southward; 5) increase in clastic composition of sediments southward (Table 2); 6) occurrence of coarse-grained clastics lower in the stratigraphic section southward; 7) interfingering of coarse-grained arkosic clastic and carbonate units in the middle third of the field area (Plate 1, clastics dominate the southern third and carbonates dominate the northern third); and 8) paleocurrent structures which indicate a southerly source (Figures 40 and 41, in Appendix F).

No known source area for Bursum Formation clastics exists between the study area and the Pedernal Hills area (Pedernal Uplift). However, anomalous thicknesses of conglomeratic Abo Formation (which includes Bursum strata in subsurface) are reported from this region. This anomaly is reported from surface exposures in the Oscura Mountains and subsurface data from the Standard of Texas No. 1, J.H. Heard Well (Spear et al., 1983).

Thus the possibility of two distinctly different source areas is indicated for the Bursum Formation clastics. These granitic and gneissic source areas include the Joyita Hills (Joyita Uplift) and a source to the south (southeast or southwest) perhaps a currently unexposed block of granitic or gneissic material.

	Site 1	Site 2	Site 3	Site 4	Site 5
Clastic/Carbonate =	4.3	1.9	6.1	7.0	9.3
> Sand / < Sand =	0.38	0.08	0.18	0.2	1.2

Table 2: Lithologic Ratios For Study Area Compiled From Field Descriptions. Clastic as used here includes all non-carbonate constituents.

SUMMARY AND CONCLUSIONS

The Bursum Formation of the study area records a transition from a dominantly marine environment to a dominantly terrestrial environment (Figure 32). This transition was accomplished by the progradation of clastics, from nearby uplifts of Precambrian and Paleozoic rocks, into a shallow, low energy, carbonate producing marine environment.

Clastic progradation in the northern third of the study area took the form of a lobate, shallow-water delta during periods of relative stability and a fan delta during periods of tectonic activity. Lobate deltas exhibit well developed and recognizable prodelta, delta-front, delta-plain, channel, and abandonment facies. In the southern third of the field area a high gradient fan delta is proposed. Fan deltas exhibit prodelta, distal-fan, mid-fan, and abandonment facies.

The close stratigraphic relationships between subaerially exposed strata and shallow marine strata indicates rapid sea-level change. Mudcracks and terrestrial plant life of delta-plain facies are preserved *in-situ* due to their rapid inundation by a marine environment. Also, the interfingering of marine and alluvial fan facies, such as debris flows, indicates a rapid sealevel change or more likely the presence of a proximal tectonic uplift.

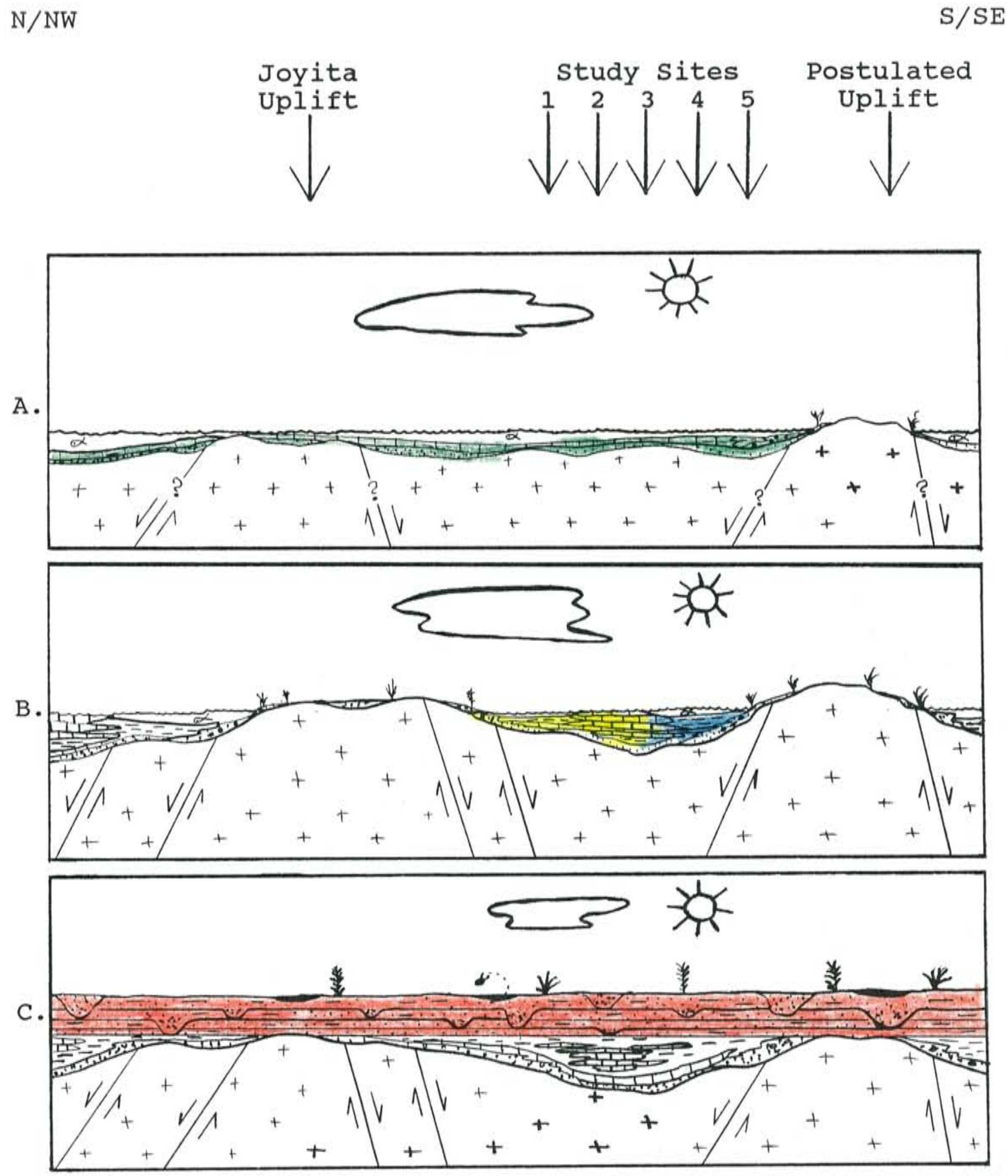


Figure 32: Author's concept of NW-SE cross-sectional relationships between Pre-Bursum Formation sediments (A. green color), Bursum sediments (B. northern section is colored yellow, southern section is colored blue), and Post-Bursum sediments (C. red color) in the study area. Note interfingering of Bursum lithologies in center of study area (diagram not to scale).

Carbonate producing environments on abandoned delta lobes range from a near normal marine salinity environment to a schizohaline environment. The diverse biotic communities of abandonment facies include both stenohaline and euryhaline organisms. In restricted, carbonate producing zones the environment is strongly influenced by temperature, salinity, and turbidity. Organisms inhabiting these restricted environments are the more tolerant euryhaline varieties.

The intimate lateral and vertical relationships of carbonate and clastic environments can be represented by many subenvironments. These subenvironments range from interdeltaic clastic shorelines to carbonate producing coasts. Strata representing this category of subenvironments are poorly exposed or not recognized within the field area.

Within the study area, deposition of the Bursum Formation deltas was confined to the early Wolfcampian. This time frame is typical for the Bursum Formation deposition throughout central New Mexico, although an earlier time frame may be indicated locally.

Two source areas for the progradation of Bursum Formation clastic deltas, during the Wolfcampian, have been proposed. The Joyita Hills (Joyita Uplift) in the north and a currently unexposed source to the south, southeast, or southwest are believed to have contributed clastics from opposing directions. Current structures and lithic characteristics verify this possibility. Eventially these source areas were leveled by erosion and buried with finer grained clastics of the Abo Formation. At that time, deposition in the transitional Bursum Formation environment ceased.

Although poorly exposed, the Bursum Formation does record many environments in the transition from a marine to a terrestrial environment.

APPENDICES

KEY TO APPENDICES

Appendices A,B, and C are prefaced with a descriptive text in order to inform the reader about parameters used to compile and evaluate field data.

The method of identifying and field locating thin section sample sites (for thin section data found in Appendices B and C) can be best summarized by looking through Appendix G. Appendix G contains locator maps and stratigraphic columns for study sites 1 through 5.

Sample site location for thin sections listed in Appendices B and C can be identified by using the site name and unit numbers found in Appendix G. For a sample like CC-19B-2 the following conventions are observed:

1. The paired letters ("CC") refer to the site (Cibola Canyon - Site 1) from which the sample is derived (see key to sites below);
2. the numerals ("19") refer to the measured unit (found in first column of Figure 43 for Site 1);
3. the alphabetical designation ("B") refers to additional samples taken from that unit ("CC-19"). Such samples are taken at some nonspecified vertical or lateral offset from other samples in the unit. Some indication of the number of samples from each unit can be determined from the column labled "Thin Section Location" on columns in Appendix G;
4. a last numeral, when present, indicates the identity of sequential thin sections made from the same sample;
5. the map location for that portion of the section (unit 19 at the Cibola Canyon site) is keyed to the letter found in the column labeled "Measured Section." Unit CC-19-B is located in section "E" in Figure 42.

A number of thin section samples compiled in Appendix D utilize this same location method. Samples with the addition of a hyphen and an alphanumeric or a numeric designation indicate a duplicate slide. Example: CC-26-1A and CC-26-1B are duplicates of CC-26, likewise DC-5A-2 is a duplicate of DC-5A. Other samples identified in Appendix D carry a verbal description of location.

Appendices E,F, and H utilize the generalized study site location scheme as referenced in Appendices A and G.

A key to site abbreviations is as follows:

CC = Cibola Canyon	(Site 1)
CU = Canyoncito de la Uva	(Site 2)
DC = Del Cuerto Area	(Site 3)
AT = Arroyo Tinajas Area	(Site 4)
CV = Cerro del Viboro Area	(Site 5)

APPENDIX A

FIELD DESCRIPTIONS FOR COMPOSITE SECTIONS

APPENDIX A

Classification Systems

Field descriptions in the text and this appendix utilize the following descriptive terminology; 1) the classification system of Pettijohn, Potter, and Siever (1972) for sandstones, 2) the classification system of Dunham (1962) for carbonates, 3) the classification system of Folk (1980) for mudrocks, 4) the classification system of Folk (1962) for carbonate thin sections, 5) bedding thickness terminology of Ingram (1954), 6) grain size terminology of Wentworth (1922), and 7) the color terminology of Goddard (1979). Other terms used are considered general and need no further systematic definition.

APPENDIX A (continued)

Site 1 - Cibola Canyon Area

E 1/2 Sec. 11 and W 1/2 Sec.12, projected, T. 1 S., R. 2 E.

Unit	Thickness (ft.)	Description
CC-27		Base of Abo Formation; comformable contact.
CC-26	0.5	CARBONATE WACKESTONE; medium light gray (N 6) to grayish-red (5R 4/2) fresh and weathered; color mottling locally; micritic; medium to fine sand grains of quartz; locally a limestone granule conglomerate; contains mollusc shell debris, fish scales, and vertebrate bone fragments; uneven, thin but variable bedding; surface is copper stained locally; weathers slabby; resistant.
CC-25	0.5	CARBONATE MUDSTONE; grayish-red (5R 4/2) fresh, medium light gray (N 6) weathered; micritic with shaly impurities; non-fossiliferous; thin, uneven, irregular bedded; weathers nodular, semi-resistant.
CC-24	3.0	CALCAREOUS CLAYSTONE; grayish-red (5R 4/2) fresh and weathered; micritic; nodular, nodules 1 inch in diameter are gray in color and increase in abundance vertically where clay partings form matrix; bedding is structureless to obscure; weathers nodular, slope former.
CC-23	14.0	CLAYSTONE; grayish-red (5R 4/2) fresh and weathered; stuctureless, obscure bedding; friable; slope former.
CC-22	0.5	CARBONATE MUDSTONE; medium light gray (N 6) fresh and weathered; micritic; contains sand size grains of quartz; sparsely fossiliferous, contains mollusc shell fragments; bedding is thin; weathers to plates, resistant.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
CC-21	2.0	CLAYSTONE; medium light gray (N 6) fresh and weathered; structureless to obscure bedding, calcareous near top; friable; slope former.
CC-20	3.0	CARBONATE MUDSTONE; medium light gray (N 6) to grayish-blue (5PB 5/2) fresh and weathered; nodular; sparsely fossiliferous, contains mollusc fragments; irregular, indistinctly bedded; nodules to 3 inches in longest dimension, in a matrix of gray calcareous clay; weathers nodular, slope former.
CC-19	1.0	CARBONATE MUDSTONE; medium light gray (N 6) fresh and weathered; mottled; contains sand size quartz grains; sparsely fossiliferous, mollusc fragments; thin-bedded; weathers slabby, resistant.
CC-18	8.0	SUBARKOSIC WACKE; grayish red-purple (5RP 5/2) fresh, pale reddish-brown (10R 5/4) weathered; uppermost portion is mottled green and contains micritic nodules up to 1 inch in longest dimension; fine sand to silt size, moderate to well sorted, angular, hemitite stained quartz grains and weathered feldspars; micaceous; thin-bedded to laminated; symetrical, linguloid, and oscillation ripples on exposed surfaces; base of unit has elongate ball and pillow type loading structures, load casts, grooves, and parting lineation on bedding planes; biogenic structures include horizontal burrows 2 inches in diameter, vertical burrows up to 0.5 inch in diameter, trails, and traces; weathers slabby to flaggy, semi-resistant.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
CC-17	7.0	CLAYSTONE; light olive gray (5Y 6/1) fresh and weathered; clay size clasts grade vertically to silt size; thin to very thin, uneven bedding; friable; weathers flaggy, slope former.
CC-16	1.5	CARBONATE WACKESTONE; light olive gray (5Y 6/1) fresh, yellowish-gray (5Y 7/2) weathered; micritic; underside of unit contains mollusc shells which are heavily encrusted with algae; underside is also heavily burrowed; medium-bedded with gray clay-shale breaks which contain 2 species of pelecypods; weathers slabby resistant.
CC-15	4.0	CLAYSTONE/CLAY-SHALE; light olive gray (5Y 6/1) fresh and weathered; contains clay to silt sized clasts; calcareous; very thin-bedded to laminated, with thin to very thin carbonate wackestone interbeds; contains several species of pelecypods found in both carbonate and claystone beds; friable, locally fissile; weathers papery, slope former.
CC-14	9.0	QUARTZ WACKE; medium light gray (N 6) fresh, moderate reddish-brown (10R 4/4) weathered; contains coarse sand to silt size, moderate to well sorted, angular, quartz grains; matrix of weathered material; micaceous; thick to very thin bedded; upper surface becomes limy; friable; weathers platy to slabby, semi-resistant.
CC-13	18.0	SILTSTONE; medium light gray (N 6) fresh and weathered; grades from clay size near the base to a moderate to well sorted, angular, sand near the top; micaceous;

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		laterally contains silicified logs and leaf impressions; very thin to thin-bedded; contains broad shallow channels filled with overlying unit; friable; weathers slabby; slope former.
CC-12	5.5	CARBONATE MUDSTONE; medium light gray (N 6) fresh and weathered; micritic; finely fossiliferous, contains fragments of brachiopods and ostracods; gray clay-shale partings between thin to medium-bedded carbonates; laterally the upper beds contain shallow, 1-2 foot thick, sandy channels with limestone cobbles up to 6 inches in long dimension, oncolitic growths are found locally in these channels; weathers slabby; resistant.
CC-11	1.5	CLAY-SHALE; medium light gray (N 6) fresh, medium gray (N 5) weathered; structureless to obscure bedding; fissile, friable; laterally missing; slope former.
CC-10	9.0	CARBONATE MUDSTONE; yellowish-gray (5Y 7/2) fresh, very light gray (N 8) weathered; micritic; nodular; nodules to 3 inches in longest dimension; finely fossiliferous, contains brachiopod and crinoid fragments; thin to very thin, irregular, uneven bedding; weathers nodular; pooly exposed; slope former.
CC-9	10.0	CARBONATE WACKESTONE; light gray (N 7) fresh, medium light gray (N 6) weathered, often has brownish surface stain; micritic; jasper replaced crinoid stems and calyx plates, echinoid spines and interambulacral plates, 10 species of brachiopods, rugose coral, 3

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		species of pelecypods, 2 species of gastropods, and sharks teeth; thick to medium, irregular, and unevenly bedded, with thin to very thin clay interbeds; the underside of carbonate beds and clay interbeds are locally horizontally burrowed in a manner similar to <u>Thalassinodes;</u> large vertical burrows, 8 inches long and 3 inches wide are found locally and are inhabited by jasperized pelecypods in growth position; basal units are micritic, uppermost beds are nodular; weathers blocky, flaggy to platy, and nodular, semi-resistant.
CC-8	7.0	CLAYSTONE; grayish red-purple (5RP 4/2) fresh and weathered with vertical color change to medium dark gray (N 4) fresh and weathered; contains micritic and clay nodules up to 2 inches in longest dimension; structureless to obscure bedding; friable, slope former.
CC-7	3.0	CARBONATE WACKESTONE; moderate grayish-purple (5P 5/2) fresh, light brownish-gray (5YR 6/1) weathered; nodular; sparsely fossiliferous, fragments of brachiopods and pelmatozoans; thin indistinct bedding; upper surface commonly sandy and jasper replaced; weathers to nodules, semi-resistant.
CC-6	11.0	CLAYSTONE; dark greenish-gray (5GY 4/1) fresh, moderate grayish-purple (5P 5/2) weathered; color mottled locally; contains clay to silt size particles; contains micritic nodules up to 2 inches in longest dimension and limy beds; structureless to obscure bedding; friable; slope former.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
CC-5	42.0	ARKOSIC SANDSTONE/SILTSTONE/MUDSTONE; moderate grayish red-purple (5RP 5/2) fresh, dusky red-purple (5RP 3/2) weathered, grades vertically to a grayish-purple (5P 5/2) claystone; basal beds often moderate olive gray (5Y 4/2) fresh, green gray (5GY 6/1) weathered, and contains micritic nodules; contains clay to coarse sand size, moderate to well sorted, angular, clasts of quartz and pink weathered feldspar; micaceous; medium-bedded to thinly laminated, graded bedding noted; locally color mottled to greenish-gray in microcross-laminations which produce fissile zones; flaggy weathering character, slope former.
CC-4	6.0	ARKOSIC SANDSTONE; grayish orange-pink (5YR 7/2) fresh, pale yellowish-brown (10YR 6/2) weathered; fine to coarse sand size grains of moderate to well sorted, angular, quartz, pink weathered feldspar; locally a limestone pebble conglomerate forms an erosional base and contains subrounded, subelongate, pebble size clasts of fossiliferous limestone, smaller granule size clasts of shale, quartz, pink feldspar, and fossil fragments; fining upward sand is common; trough, tabular, and wedge-shaped cross-beds of medium to large-scale, high-angle, cosets with sharp, erosional, lower contacts found locally; laterally becomes planar stratified and medium to thin-bedded; weathers to rounded blocky masses; resistant.
CC-3	2.0	CLAYSTONE; dusky red-purple (5RP 3/2) fresh, grayish red-purple (5RP 4/2) weathered; inversely grades from fine sand to clay; structureless to

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		obscurely bedded; poorly exposed; slope former.
CC-2	2.0	SILTSTONE/ARKOSIC SANDSTONE; medium brownish-gray (5YR 5/1) fresh, grayish-red (10R 4/2) weathered; grades from fine silt to medium arkosic sand, laterally contains coarse sand to cobble size limestone cobbles and merges vertically with the overlying unit; micaceous; medium to thin planar bedding; color laminated locally; poorly exposed; weathers blocky to flaggy; semi-resistant.
CC-1	2.0	CLAYSTONE; dusky red-purple (5RP 3/2) fresh, grayish red-purple (5RP 4/2) weathered; lower 1/2 contains micritic nodules up to 2 inches in longest dimension which contain fusulinid fauna; structureless to obscure bedding; color mottling locally present; poorly exposed; slope former.
CC-0	0.0	Top of Moya Formation; gradational contact. Unit not described.
Total	173.0	

APPENDIX A (continued)

Site 2 - Canoncito de la Uva Area

SW 1/4 Section 1 and W 1/2 Section 12, T. 2 S., R. 2 E.

Unit	Thickness (ft.)	Description
CU-42		Base of Abo Formation; contact locally conformable.
CU-41	1.0	CARBONATE MUDSTONE; medium gray (N 5) fresh, light olive gray (5Y 5/2) weathered; micritic; contains sand to clay size terrigenous debris; medium to thin-bedded; lateral variation is rounded limestone and mudrock pebbles with sand size quartz grains; weathers slabby to nodular; resistant.
CU-40	17.0	CLAYSTONE/CLAY-SHALE; olive gray (5Y 4/1) fresh, light olive gray (5Y 6/1) weathered in the lower 3/4 and pale red (10R 6/2) fresh and weathered in the upper 1/4; tubular burrows (?) 2 inches in diameter with micritic and sparry internal structure occur locally in the upper 1/4, structureless to obscure bedding; friable, locally fissile; slope former.
CU-39	1.5	CARBONATE WACKESTONE; medium gray (N 5) fresh, grayish-orange (10YR 7/4) weathered; micritic; contains the fossilized gastropods Bellerophon and Pharkidontus; medium-bedded; laterally becomes impure and nodular; weathers blocky; resistant.
CU-38	9.0	CLAYSTONE/CLAY-SHALE; olive gray (5Y 4/1) fresh, light olive gray (5Y 6/1) weathered; contains clay to silt sized clasts; thin discontinuous limy lenses contain fossil pelecypods, gastropods, and a variety of vertebrate remains, a nodule containing the skeletal remains of a fish was found in this

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		unit; silicified trees, associated coaly lenses and fist sized hemitite-gypsum replacements of these are found locally; structureless to obscure bedding in claystones, thin to very thin-bedded limestone; friable, locally fissile; slope former.
CU-37	1.0	CARBONATE MUDSTONE; medium gray (N 5) fresh, grayish orange (10YR 7/4) weathered; micritic; with clay sized impurities; contains several species of pelecypods; medium-bedded; weathers nodular to slabby; resistant.
CU-36	15.0	CLAYSTONE/CLAY-SHALE; basal beds are dark reddish-brown (10R 3/4) fresh, pale red (10R 6/2) weathered and upper beds are olive gray (5Y 4/1) fresh, light olive gray (10Y 6/1) weathered; structureless to obscure bedding; laterally thin, discontinuous, lenses of nodular limestone; friable; locally fissile; weathers shaly to flaggy; slope former.
CU-35	4.0	CARBONATE MUDSTONE; medium light gray (N 6) fresh and weathered; mottled; locally upper beds weather to a grayish-orange (10YR 7/4) surface stain, and are iron carbonate (siderite); sandy with quartz and feldspar grains; thick to very thick-bedded; weathers somewhat nodular but typically massive to blocky, resistant.
CU-34	3.0	CLAYSTONE; light gray (N 7) fresh and weathered; structureless to obscurely bedded; contains micritic nodules; friable; poorly exposed; slope former.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
CU-33	8.0	SUBARKOSE; very pale orange (10YR 8/2) fresh, pale brown (5YR 5/2) to pale yellowish-brown (10YR 6/2) weathered; contains hematite blebs; medium to coarse grains of well sorted, subrounded to rounded, quartz and pink weathered feldspar; fining upward sand common; thin- to thickly-bedded, locally high angle trough and tabular cosets of medium to large-scale cross-beds; rip up clasts of underlying carbonate and claystone units are seen locally; uppermost surface is limy; exposed upper surfaces are darkly stained and contain fossilized logs; well indurated; resistant.
CU-32	1.8	CLAYSTONE; light gray (N 7) fresh and weathered; stuctureless to obscurely bedded; silty; missing laterally; poorly exposed; slope former.
CU-31	1.4	CLAYSTONE; light grey (N 7) fresh and weathered; contains micritic nodules up to 1 inch in diameter; structureless to obscurely bedded; silty; missing laterally; poorly exposed; slope former.
CU-30	2.9	CARBONATE MUDSTONE; light gray (N 7) fresh and weathered; mottled; micritic; silty; thin to medium bedded; missing laterally; poorly exposed; semi-restistant.
CU-29	2.8	CARBONATE MUDSTONE; light brownish-gray (5YR 6/1) fresh; pale brown (5YR 5/2) weathered; contains medium sand size grains of quartz and pink feldspar; medium-bedded; missing laterally; poorly exposed, semi-resistant.
CU-28	4.5	SILTSTONE; grayish-red (10R 4/2) fresh and weathered; silt to very fine

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		sand clasts; locally tan to green mottling; micaceous; thin-bedded to laminated; laterally missing; weathers friable, locally fissile; slope former.
CU-27	4.1	ARKOSIC SANDSTONE; pale red (10R 6/2) fresh, grayish-red (10R 4/2) to pale brown (5YR 5/2) weathered; fine to medium sand size clasts of moderate to well sorted, subrounded, quartz, pink feldspar and white weathered feldspar; silty; very thin to thick-bedded with lateral zones of low and high angle medium-scale trough and tabular-shaped crossbeds; thin-bedded zone near base contains interference and oscillation ripples, sole marks, parting lineation, and vertical burrows 0.25 inch in diameter; laterally grades into a calcareous sand unit that exhibits convolute cross-bedding, oversteepened cross-bedding, and small channels with carbonate rip up clasts and fossile fragments; weathers flaggy.
CU-26	1.9	CLAYSTONE; light gray (N 7) fresh and weathered; structureless to obscurely bedded; contains micritic nodules; poorly exposed; slope former.
CU-25	1.5	CARBONATE MUDSTONE; light gray (N 7) fresh, light olive gray (5Y 6/1) weathered; micritic; sparsely fossiliferous, contains fragments of brachiopods and crinoids; thin bedded; poorly exposed; resistant.
CU-24	0.5	MUDSTONE; light gray (N 7) fresh and weathered; structureless to obscurely bedded; poorly exposed; slope former.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
CU-23	2.9	CARBONATE MUDSTONE; medium dark gray (N 4) fresh, grayish orange-pink (5YR 7/2) weathered; micritic to sparry; sparsely fossiliferous, contains brachiopod and mollusc fragments; contains a pebbly upper surface of well to very well sorted, well rounded, limestone clasts; medium to thick-bedded; weathers blocky; resistant.
CU-22	36.5	CLAYSTONE; dark reddish-brown (10R 3/4) fresh, grayish red-purple (5RP 4/2) weathered with color changing vertically to greenish-gray (5GY 6/1) fresh and olive gray (5Y 4/1) weathered; contains greenish streaks locally; stuctureless to obscurely bedded; thin lenses of arkose are found near the base and in lower 1/3; micritic nodules are found in upper 1/3; wavy upper contact; friable; slope former.
CU-21	2.0	CARBONATE MUDSTONE; pale grayish red-purple (5RP 5/2) fresh and weathered; micritic; sparsely fossiliferous, contains fragments of brachiopods, molluscs, and crinoids; bedding thin to medium but indistinct; weathers nodular; resistant.
CU-20	6.5	CARBONATE MUDSTONE; pale grayish red-purple (5RP 5/2) fresh and weathered; micritic; nodular, nodules increase in size from 0.5 inch to 3 inches in longest dimension vertically; thin purplish clay stringers fill internodular zones; fossil fragments of brachiopods, crinoids, and molluscs locally abundant; bedding thin but indistinct; weathers nodular; semi-resistant.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
CU-19	14.0	CLAYSTONE/CLAY-SHALE; pale grayish-blue (5PB 5/2) fresh, pale purple (5P 6/2) weathered; contains greenish streaks and is locally mottled; bedding is structureless to obscure; becomes limy vertically, contains thin nodular limestone beds, and grades into overlying nodular limestone; friable; locally fissile; slope former.
CU-18	1.2	CARBONATE MUDSTONE; pale grayish-blue (5PB 5/2) fresh, pale purple (5P 6/2) weathered; micritic with clay to silt size particles; slightly nodular; sparsely fossiliferous, contains brachiopd, crinoid and mollusc fragments; thin purple shale break at base and a limestone granule conglomerate at the upper surface; weathers blocky to nodular; resistant.
CU-17	1.5	CARBONATE MUDSTONE; medium light gray (N 6) fresh, light olive gray (5Y 6/1) weathered; micritic with clay to silt size particles; slightly nodular, with nodules to 2 inches in longest dimension; sparsely fossiliferous, mostly detrital fragments of brachiopods, crinoids, and molluscs; thin-bedded but indistinct; weathers unevenly to nodular; resistant.
CU-16	2.0	CARBONATE MUDSTONE; grayish-blue (5PB 5/2) fresh and weathered; locally mottled and streaked with green; nodular, nodules up to 1.5 inches in diameter; internodular fill is a purple shale; sparsely fossiliferous, with fossil abundance decreasing vertically, fossil fragments include brachiopods, molluscs, and crinoids; bedding is

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		thin to medium but indistinct; weathers nodular; semi-resistant.
CU-15	7.9	CARBONATE MUDSTONE; medium light gray (N 6) fresh, light olive gray (5Y 6/1) weathered; micritic to impure; jasper replaced fossils include echinoid spines and interambulacral plates, crinoid stems, the brachiopods *Antiquatonia*, and *Neospirifer*, bryozoans, ostracods, and pelecypods; thin- to medium bedded; contains interbedded, thinly bedded, green-gray shales; weathers slabby to nodular; semi-resistant.
CU-14	32.0	CARBONATE MUDSTONE/SILTSTONE/ CLAYSTONE/CLAYSHALE; medium dark gray (N 4) to light olive gray (5Y 6/1) fresh, and medium light gray (N 6) to pale olive gray (10Y 6/2) weathered; micritic; minor iron carbonate (siderite) interbeds; interbedded micritic limestones, fine-grained sandstones, siltstones, claystones, and clay-shales; mostly sparsely fossiliferous except for a zone at midpoint which contains hematite encoated and replaced scaphopods and bellerophon gastropods; bedding is thin to very thin; lower 1/3 contains irregular uneven beds of thin algal laminations; siltstone in upper 1/3 contains cross-laminae and disrupted cross-bedding; weathers flaggy to slabby; slope former.
CU-13	6.5	CARBONATE MUDSTONE; medium dark gray (N 5) fresh, medium gray (N 6) weathered; mottled; micritic; sparsely fossiliferous, detrital fragments of brachiopods; dark gray to black, platy to spherical, cherty looking areas; laterally traced to algal mats with ripup clasts

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		and birdseye structures; thick bedded; weathers blocky; resistant.
CU-12	6.0	CARBONATE MUDSTONE/DOLOSTONE; medium light gray (N 6) fresh, yellowish gray (5Y 7/2) to light olive gray (5Y 6/1) weathered, mottled; micritic; locally dolomitic; sparsely fossiliferous, mostly detrital brachiopod fragments, some crinoid fragments; thick to very thick-bedded; weathers to massive blocks; resistant.
CU-11	5.0	CARBONATE MUDSTONE/DOLOSTONE; dark yellowish-orange (10YR 6/6) to medium light gray (N 6) fresh and weathered, mottled; micritic; dolomitic; contains fossiliferous shaly interbeds and laterally bifurcates; sparsely fossiliferous; uneven thin to medium-bedded; laterally contains zones of fossil debris in bedding planes; weathers blocky; resistant.
CU-10	4.0	CARBONATE MUDSTONE/WACKESTONE; medium gray (N 5) fresh, light olive gray (5Y 6/1) weathered; contains jasper replaced pelmatazoan hardparts, the brachiopods *Composita ovata*, *Neochonetes*, *Juresania*, *Antiquatonia*, *Crurithyris planoconvexia*, *Linoproductus*, *Neospirifer*, *Punctospirifer* and *Composita subtilita*, other forms include digitate and encrusting bryozoans, solitary rugose corals, ostracods, pelecypods, and vertebrate remains; typically thin-bedded; interbedded gray claystone dominates upper 1 foot; weathers slabby; semi-resistant.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
CU-9	5.0	CARBONATE MUDSTONE/CALCAREOUS CLAYSTONE; medium gray (N 5) fresh, light olive gray (5Y 5/2) weathered; micritic with clay impurities, contains the brachiopods <u>Juresania</u>, <u>Neochonetes</u>, and <u>Planoconvexia</u>, other fossil forms include crinoid columnals, byrozoans, and small solitary rugose corals; some jasper replacement of fossils noted; medium to thin evenly-bedded with interbeds of gray calcareous claystone; unit becomes thicker bedded vertically; poorly exposed; weathers slabby; slope former.
CU-8	42.0	CLAYSTONE/ SILTSTONE; light gray (N 7) fresh and weathered with local zones in the lower 1/2 colored pale purple (5P 6/2); locally calcareous; clay to silt size clasts; lower 1/2 contains several thin, less than 6 inches thick, calclithite beds which contain moderate to well sorted, subangular to rounded, sand size clasts of limestone, quartz, and pink feldspar; structureless to obscurely bedded; contains irregular sphere to disk-shaped micritic nodules up to 12 inches in longest dimension; friable; slope former; poorly exposed.
CU-7	2.0	CALCLITHITE; medium gray (N 6) fresh, medium dark gray weathered with a pale brown (5YR 5/2) surface stain; consists of rounded to subrounded, subelongate to spherical carbonate pebbles up to 3 inches in diameter, smaller shaly and sandy clasts, and medium to coarse sand grains of quartz, pink feldspar, and fossil fragments; medium-bedded; locally capped with a variable thickness of medium light-gray (N 6)

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		fresh, medium brown-gray (5YR 5/1) weathered sand which is composed of well sorted, subangular to rounded, quartz and pink feldspar; weathers blocky; resistant.
CU-6	3.0	CLAYSTONE; very light gray (N 8) fresh, white (N 9) weathered; clay sized particles which have a gypsum or caliche weathering character; structureless to obscurely bedded; poorly exposed; slope former.
CU-5	3.0	CARBONATE MUDSTONE; light gray fresh (N 7), medium gray (N 5) weathered, with a brown surface stain; micritic to sparry; nodular, nodules to 3 inches in longest dimension; abundant fusulinid fauna; uneven, irregular bedding, with interbedded clay; weathers nodular; semi-resistant.
CU-4	13.7	CLAYSTONE, grayish red-purple (5RP 4/2) fresh, moderate grayish purple (5P 5/2) weathered, changes color vertically to dark red (5R 2/6) fresh and grayish-red (5R 4/2) weathered; mottled and contains greenish streaks; clay to mud size particles; contains micritic nodules; structureless to obscurely bedded; friable; slope former.
CU-3	1.4	SILTSTONE/SUBARKOSIC SANDSTONE; moderate grayish-purple (5P 5/2) fresh, grayish red-purple (5RP 4/2) weathered; color lamination in lower 1/2 of unit; silt to very fine sand size grains; medium-bedded; weathers blocky; resistant.
CU-2	9.0	SILTSTONE/CLAYSTONE; dark olive gray (5Y 3/1) fresh and light gray (N 7) weathered with lateral variation of

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		grayish-red (5R 4/2) fresh and weathered; clay to silt size particles; micritic nodules seen in lower 1/2; structureless to obscurely bedded; friable; slope former.
CU-1	1.0	CLAYSTONE/SILTSTONE; dusky red-purple (5RP 3/2) fresh and weathered; nodules of micritic, sparsely fossiliferous limestone in a matrix of claystone, nodules are up to 3 inches in longest dimension; very thin to structureless bedding; unit is variable in thickness; weathers nodular; rubbly slope former.
CU-0	0.0	Top of the Moya Formation; conformable, gradational contact.
Total	289.0	

APPENDIX A (continued)

Site 3 - Del Cuerto Area

NW 1/4 Sec. 27, T. 2 S., R. 2 E.

Unit	Thickness (ft.)	Description
DC-23		Base of the Abo Formation; gradational, conformable contact.
DC-22	0.2	ARKOSIC SANDSTONE/CALCLITHITE; medium gray (N 5) fresh and weathered with yellowish clasts (10YR 8/6); coarse to very coarse-grained, angular to rounded, moderate to poorly sorted, limestone, shale, quartz, and weathered feldspar clasts; grades laterally to limestone granule conglomerate; no bedding structures; poorly exposed; semi-resistant.
DC-21	3.0	CLAYSTONE; light gray (N 7) fresh and weathered; clay to silt sized particles; obscure to structureless bedding; contains tubular-shaped nodules, 2 inches in diameter, which have micritic to sparry interior; poorly exposed; friable; slope former.
DC-20	1.0	ARKOSIC SANDSTONE/CALCLITHITE; medium gray (N 7) fresh and weathered with yellowish (10YR 8/6) clasts; poor to moderately sorted, subangular to rounded, coarse to very coarse grained quartz, weathered feldspar, limestone, and shale clasts; grades laterally to limestone granule conglomerate; contains numerous blebs of hematite and nodules of hematite after crystalline pyrite; locally trough cross-bedded; laterally missing; poorly exposed; semi-resistant.
DC-19	10.0	CLAYSTONE; light gray (N 7) fresh, light olive gray (5Y 6/1) weathered, vertically grades to a grayish-red (10R 4/2); contains micritic nodules; obscure to structureless

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		bedding; poorly exposed; friable; slope former.
DC-18	1.0	CALCILITHITE; medium olive gray (5Y 5/1) fresh, pale brown (5YR 5/2) weathered with dark yellow-orange (10YR 6/6) colored clasts; contains poorly sorted, well rounded, pebble size carbonate clasts which grade laterally to coarse arkosic composition; medium-bedded; weathers slabby; resistant.
DC-17	5.0	CLAYSTONE; light olive gray (5Y 6/1) fresh, very light gray (N 8) weathered; clay to silt size particles; bedding obscure to structureless; poorly exposed; friable; locally fissile; slope former.
DC-16	5.0	SUBARKOSIC SANDSTONE; very pale orange (10YR 8/2) fresh, pale yellowish-brown (10YR 6/2) to dark yellowish-brown (10YR 4/2) weathered, with a dark brown surface stain common; inversely graded from coarse sand size to pebble size, poorly to well sorted, subangular to subrounded, quartz, weathered feldspar, mudrocks, and carbonate clasts; contains hematite blebs in pore areas and hematite roses after pyrite on bedding surfaces; upper surface locally an arkosic pebble conglomerate; thick to very thickly bedded with medium-scale trough and tabular cross-beds which trend to the north; upper surface has tree and vertebrate fragments; weathers blocky to massive; resistant.
DC-15	5.0	CARBONATE MUDSTONE/CALCAREOUS SANDSTONE; grayish orange-pink (5YR 7/2) fresh, light brown (5YR 5/6) weathered; mottled;

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		micritic and nodular with coarse to medium, subrounded, subangular, quartz and pink-orange feldspar grains; decrease in sand content vertically; contains fine-grained detrital fragments of brachiopods and molluscs; thin to thick-bedded, convolute cross-bedded; lateral variations include a clean micritic limestone, a mottled purple-gray impure limestone, and a channel filled with limestone pebbles, quartz and feldspar sands, and vertebrate remains (shark teeth); weathers blocky to massive; resistant.
DC-14	29.0	CLAYSTONE; gray-red (5R 4/2) fresh, grayish-red (5R 5/2) weathered; clay to silt size particles; structureless to obscurely bedded; friable; slope former.
DC-13	14.0	CARBONATE MUDSTONE; medium light gray (N 6) fresh, light gray (N 7) weathered; upper beds are mottled dark gray and grade to a grayish-red mottled color; micritic with interbedded friable clay to silt layers; jasper replaced crinoid stems, echinoid spines and interambulacral plates, and the brachiopods _Linoproductus_ and _Neospirifer_; thin to medium-bedded; weathers slabby; resistant.
DC-12	4.0	ARKOSIC SANDSTONE/SILTSTONE; medium brown-gray (5YR 5/1) fresh, grayish-red (10R 4/2) weathered, color change laterally to pale yellow-brown (10YR 6/2); medium sand to silt size clasts of moderate to well sorted, subangular to subrounded, quartz and feldspar; thin to medium-bedded with local areas of color lamination; high to

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		low angle, medium-scale, trough and tabular cross-beds; oscillation ripples; weathers flaggy; semi-resistant.
DC-11	8.0	CLAYSTONE/SILTSTONE; light gray (N 7) fresh and weathered; clay to silt size particles; calcareous, with micritic nodules 1 inch in diameter; grades vertically into overlying unit; thin-bedded; poorly exposed; friable to fissil; slope former.
DC-10	1.0	CARBONATE MUDSTONE; light gray (N 7) fresh, medium light gray (N 6) weathered; mottled; micritic; thin to medium-bedded; locally sandy; non-fossiliferous; weathers slabby; semi-resistant.
DC-9	0.5	CALCAREOUS CLAYSTONE; light medium gray (N 5) fresh and weathered; clay to silt size particles; laterally grades to a carbonate mudstone; thin-bedded; poorly exposed, slope former.
DC-8	6.0	ARKOSIC SANDSTONE/SILTSTONE; medium brown-gray (5YR 5/1) fresh, grayish-red (10R 4/2) weathered, lateral color change to pale yellow-brown (10YR 6/2), and capped by a fine-grained sandstone which is pale yellow-orange (10YR 8/6) fresh, dark yellow orange (10YR 6/6) weathered; locally mottled to color laminated; medium sand to silt sized clasts of moderately to well sorted, subangular to subrounded, quartz and pink feldspar; medium-bedded to laminated; high and low angle, medium-scale, trough and tabular cross-beds; ripple marked; contains small channels; horizontal burrows to 0.5 inch in diameter on underside of unit; lower beds have groove

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		marks and contain limestone pebble to cobble conglomerates locally; micritic nodules in upper beds; locally fissile; weathers flaggy to platy; semi-resistant.
DC-7	2.5	CARBONATE MUDSTONE; medium dark gray (N 4) fresh, medium light gray (N 6) weathered; micritic with thin shaly partings; mottled; algal laminated, and containing rip up clasts of algal mats; thin to laminated, wavy, irregular bedded; fetid odor when broken; weathers platy; semi-resistant.
DC-6	63.0	CLAYSTONE/SILTSTONE, basal beds are grayish-red (5R 4/2) fresh and weathered with remainder of unit typically medium olive gray (5Y 5/1) fresh, yellowish-brown (10YR 6/4) weathered; clay to fine silt size particles; calcareous; lower 1/3 is a claystone to siltstone and contains leaf impressions and oxidized coaly tree material, middle 1/3 contains spheroid to discoid, micritic to spar filled septarian nodules up to 2 feet in diameter, and thin carbonate beds with hematite coated and replaced scaphopods, gastropods, pelecypods, and several species of cephalopods; typically obscure to structureless bedding; friable; slope former.
DC-5	3.0	CALCILITHITE; medium gray (N 5) fresh, light olive gray (5Y 6/1) weathered; equant to subelongate, rounded to subrounded, poorly sorted, cobble size limestone and mudrock clasts with sand sized clasts of quartz, pink feldspar, chert, and fossil fragments of crinoid columnals, brachiopods, and fusulinids; carbonate clasts are fossiliferous

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		often fusulinid rich; laterally the erosive base of this unit is in contact with an underlying locally missing fusulinid wackestone which is light olive gray (5Y 6/1) fresh and light gray (N 7) weathered; medium to thick-bedded; weathers blocky; resistant.
DC-4	4.0	CLAYSTONE/SILTSTONE; grayish-red (5R 4/2) fresh, dark reddish-brown (10R 3/4) weathered; mottled and contains greenish streaks locally; clay to silt size clasts; contains gray to purple micritic nodules up to 2 inches in diameter; obscure to structureless bedding; friable; slope former.
DC-3	2.5	SUBARKOSIC SANDSTONE/SILTSTONE, grayish-red (5R 4/2) fresh, dark reddish-brown (10R 3/4) weathered; locally light brown to light green and mottled; medium sand to silt size clasts of poorly to well sorted, angular to subrounded, quartz and feldspar; locally micaceous; vertical burrows up to 0.5 inches in diameter can be seen on bedding surfaces; thin to very thin-bedded; weathers slabby to flaggy; semi-resistant.
DC-2	1.0	CLAYSTONE; grayish-red (5R 4/2) fresh, dark reddish-brown (10R 3/4) weathered; clay to silt size clasts; grades into overlying and underlying units; bedding is obscure to structureless; friable; slope former.
DC-1	1.5	CARBONATE WACKESTONE/CLAYSTONE; grayish-red (5R 4/2) fresh, dark reddish-brown (10R 3/4) weathered; clay to silt size clasts; fossiliferous micritic nodules 2 to

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		3 inches in diameter decrease vertically; bedding is obscure to structureless; friable; slope former.
DC-0	0.0	Top of Moya Formation; gradational, conformable contact.
Total	170.2	

APPENDIX A (continued)

Site 4 - Arroyo Tinajas Area

E 1/2 Sec. 5 and W 1/2 Sec. 4, T. 3 S., R. 2 E.

Unit	Thickness (ft.)	Description
AT-25		Base of the Abo Formation; erosional contact.
AT-24	6.0	CLAYSTONE, light gray (N 7) fresh, pale purple (5P 7/2) weathered; clay to silt size clasts; micritic nodules up to 2 inches in diameter increase in abundance vertically; bedding obscured to structureless; friable; poorly exposed; slope former.
AT-23	4.0	ARKOSIC SANDSTONE; pale reddish-brown (10R 5/4) fresh, moderate red-orange (10R 6/6) weathered, darker surface stain locally, brownish-gray (5YR 4/1); coarse sand to pebble size, poorly sorted, angular clasts of quartz, pink and orange feldspar, and granite; coarsest grain size commonly on upper surface; thick- to very thickly bedded; medium-scale trough and tabular cross-beds of high angle; well indurated; resistant.
AT-22	14.0	CLAYSTONE; light gray (N 7) fresh and weathered; clay to silt sized clasts; micritic nodules up to 2 inches in diameter; bedding obscure to structureless; friable; poorly exposed; slope former.
AT-21	3.5	ARKOSIC SANDSTONE; pale red (5R 6/2) fresh, pale reddish-brown weathered, darker surface stain locally, grayish-brown (5YR 4/1); coarse sand to pebble size, poor to moderate sorted, angular clasts of quartz, pink and orange feldspar, and granite; thick-bedded; medium-scale trough and tabular cross-beds of

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		high angle not well defined; well indurated; resistant.
AT-20	1.0	CARBONATE WACKESTONE; light gray (N 7) fresh and weathered; micritic with fossil fragments; thin to medium bedded; resistant.
AT-19	3.0	CLAYSTONE; light gray (N 7) fresh and weathered; clay to silt size clasts; bedding obscured; friable; poorly exposed; slope former.
AT-18	1.0	CARBONATE MUDSTONE; very light gray (N 8) fresh and weathered; micritic; nodular with nodules up to 2 inches in long dimension; locally silt to medium sand size clasts of quartz and pink feldspar, contains a fine grained fossil assemblage, thinly interbedded with light gray claystone, friable, slope former.
AT-17	0.5	CARBONATE MUDSTONE; pinkish-gray (5YR 8/1) fresh, very light gray (N 8) weathered; medium to coarse sand size clasts of quartz and pink feldspar; thin-bedded; fossiliferous; semi-resistant.
AT-16	3.0	ARKOSIC SANDSTONE; pale red (5R 6/2) fresh, pale reddish-brown (10R 5/4) weathered; coarse sand to cobble size clasts of poorly sorted, angular, quartz, orange and pink feldspar, and granite; micaceous; medium-scale trough and tabular cross-beds of high angle poorly defined, very thick-bedded, well indurated, resistant.
AT-15	5.0	CARBONATE MUDSTONE; medium light gray (N 7) fresh and weathered; micritic and nodular with nodules up to 1 inch in diameter; internodular area is clay size clasts with local clay

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		pockets; contains the brachiopods <u>Neospirifer</u>, <u>Composita subtilita</u>, and <u>Neochonetes</u>, pelecypods, crinoids, and bryozoans; branching horizontal burrows up to 0.5 inches in diameter are found; bedding is thin to structureless; may become more shaly laterally; uppermost 2 inches is a sandy, silty layer; weathers nodular; semi-resistant; slope former.
AT-14	2.5	CARBONATE MUDSTONE; medium gray (N 5) fresh and weathered; mottled with grayish red-purple (5RP 4/2); micritic nodules up to 2 inches in diameter; horizontal burrows to 2 inches in diameter; becomes a pelecypod packestone locally with pelecypods up to 6 inches in long dimension; other fossil forms noted include brachiopods, bryozoans, and crinoids; bedding is medium to obscured; weathers nodular; semi-resistant.
AT-13	6.0	CLAYSTONE/CALCAREOUS CLAYSTONE; dusky red (5R 3/4) fresh, gray-red (5R 4/2) weathered; clay to silt size clasts; contains numerous micritic nodules up to 2 inches in diameter; nodules decrease in abundance vertically, bedding obscure to structureless; friable; slope former.
AT-12	4.0	CARBONATE MUDSTONE; light olive gray (5Y 6/1) to grayish-purple (5P 5/2) fresh, light gray (N 7) to grayish red-purple (5RP 4/2) weathered; mottled; contains clay to sand sized clasts in stringers; jasper replaced zones subparallel to bedding planes noted locally; medium to thin bedded; laterally capped with a silty to sandy layer, grayish-red

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		(5R 4/2) and/or a dolomite layer, grayish-orange (10 YR7/4); weathers to nodules 3 inches in long dimension locally; medium to thick bedded; grades into overlying unit; semi-resistant.
AT-11	28.5	CLAYSTONE; light gray (N 7) fresh and weathered; clay to silt size clasts; coaly lenses noted in lower 1/3 of unit; structureless to obscured bedding; friable; poorly exposed; slope former.
AT-10	7.5	CLAYSTONE; light olive gray (5Y 6/2) fresh, yellowish-gray (5Y 7/2) weathered; clay to silt size clasts of orange to pink feldspar and thin arkosic lenses noted locally; obscure to thin-bedded; friable; poorly exposed; slope former.
AT-9	1.5	CALCILITHITE; medium light gray (N 7) fresh and weathered, with pinkish grains and a brownish-gray (5YR 4/1) surface stain; mottled appearance due to cobble clasts; poorly sorted, subrounded to rounded, subelongate to equant, fossiliferous carbonate pebbles and cobbles in a matrix of medium to coarse-grained quartz, orange feldspar, and fossil fragments; a capping layer of coarse to fine sand contains woody impressions and fragments; laterally is seen to interfinger with a thicker, isolated, poorly exposed body of red arkosic sandstone, contains copper (chalcocite) blebs and oxides (azurite and malachite) in this zone that are closely associated with organic material; thin to thick-bedded; well indurated; resistant, ledge former.

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
AT-8	3.0	SUBARKOSIC SANDSTONE; pinkish-gray (5YR 8/1) fresh, grayish orange-brown (5YR 7/4) weathered; poorly sorted, subangular to subrounded, coarse sand to pebble size clasts of quartz, pink and orange feldspar, chert, mudrock, and granite fragments; medium-scale trough and tabular cross-beds of high angle are poorly defined; erosional to gradational upper and lower contacts with some interbedding of both seen laterally; laterally grades to an isolated red sandstone body and contains minor copper mineralization at this locality, especially at upper contact; locally contains numerous hematite blebs on fresh surfaces and exposed bedding surfaces; typically well indurated but locally poorly indurated; thick to very thickly bedded; locally at base becomes friable; resistant, ledge former.
AT-7	2.5	ARKOSIC WACKE; greenish-black (5GY 2/2) to grayish yellow-green fresh, olive black to dusky yellow-green (5GY 5/2) weathered, both with pink specks; coarse sand to pebble size clasts of fresh unweathered orange and pink feldspars, quartz, chert, mudrock, and granite in a matrix of dark green clay to silt size paste; grains are angular and poorly sorted; contains poorly defined high angle tabular cross-beds; medium to thick-bedded; well indurated to friable; resistant, ledge former.
AT-6	13.0	CLAYSTONE; bottom 1/2 is a pale red-purple (5RP 6/2) to grayish-red (5R 4/2) fresh and weathered, grades vertically to olive gray (5Y 4/1) fresh and light gray weathered (N 7); contains micritic nodules up

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		to 1 inch in long dimension; upper contact is erosional with overlying unit; structureless to obscurely bedded; friable; slope former.
AT-5	1.5	CARBONATE MUDSTONE; very dusky red-purple (5RP 2/2) fresh, pale red-purple (5RP 6/2) weathered; mottled with light gray (N7); nodular, nodules up to 2 inches in long dimension; sparsely fossiliferous; internodular area filled with clay; bedding obscured; weathers nodular; poorly exposed; semi-resistant.
AT-4	1.5	CARBONATE MUDSTONE, very dusky red-purple (5RP 2/2) fresh pale red-purple (5RP 6/2) weathered; mottled light gray (N 7); nodular, nodules up to 1 inch in long dimension; locally a fusulinid packstone, contains fine-grained fossil hash; internodular area filled with clay; bedding obscured; weathers nodular; poorly exposed; semi-resistant.
AT-3	18.0	CLAYSTONE; bottom 1/2 is dark reddish-brown (10R 3/4) fresh and weathered, top 1/2 is pale purple (5P 6/2) to light gray (N 7) fresh and weathered; clay to silt size clasts; contains micritic nodules up to 1/2 inch in diameter; bedding is obscured; friable; slope former.
AT-2	2.5	ARKOSIC SANDSTONE/SILTSTONE; grayish-red (5R 4/2) fresh and weathered; silt to medium sand size clasts of angular, moderatly sorted, quartz, and pink feldspar; locally micaceous; grades laterally to an 8 foot thick channel sand which is filling channels eroded into the Moya Formation, these channels have

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		medium-scale trough and tabular coset cross-beds of low angle, sand from this unit fills burrows and cracks in the exposed Moya surface, horizontal burrows found on the underside of siltstone overlying claystone, medium-bedded to laminated; locally friable; weathers platy; semi-resistant.
AT-1	2.5	CLAYSTONE; dark reddish-brown (10R 3/4) fresh and weathered, with purple-gray micritic nodules; clay to silt size clasts; the unfossiliferous nodules decrease vertically and are up to 3 inches in diameter; bedding is obscure; laterally this unit is missing due to erosion; friable; slope former.
AT-0	0.0	Moya Formation; gradational to locally erosional contact.
Total	135.5	

APPENDIX A (continued)

Site 5 - Cerro del Viboro Area

W 1/4 Sec. 17, T. 4 S., R. 2 E.

Unit	Thickness (ft.)	Description
CV-12		Base of Abo Formation; conformable, locally erosional.
CV-11	5.0	CARBONATE MUDSTONE; light gray (N 7) fresh, light orange-gray-brown (5YR 6/1) weathered; micritic, nodules up to 1 inch in longest dimension; sparsely fossiliferous, contains brachiopod and mollusc fragments; internodular claystone increasing vertically until dominant; obscure bedding; weathers nodular; poorly exposed; slope former.
CV-10	5.0	CARBONATE MUDSTONE; medium light gray (N 6) fresh, light brownish-gray (5YR 6/1) weathered; micritic; nodular, nodules up to 4 inches in longest dimension; fossiliferous, locally a fusulinid packestone; irregular, uneven, thin-bedding; semi-resistant; slope former.
CV-9	3.0	CARBONATE MUDSTONE; light olive gray (5Y 6/1) fresh, brownish-gray (5YR 4/1) weathered; medium sand size grains of subangular, subrounded quartz; sand content increases vertically; fossiliferous, contains pelecypod and brachiopod shell fragments; upper surface is a calcareous sandstone that weathers dark brown; thick-bedded; resistant, ledge former.
CV-8	55.5	ARKOSIC SANDSTONE; light greenish-gray (5G 8/1) to light grayish-brown (5YR 6/1) fresh, moderate orange pink (10R 7/4) to grayish-brown (5YR 3/2) weathered; coarse sand to cobble size clasts of poorly sorted, angular to subrounded quartz, pink

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		and orange feldspar, granite, and gneiss; slope cover areas are believed to be claystone and/or friable zones of arkose; beds are thick to very thick and laterally pinch and swell; medium-scale trough and tabular coset cross-beds of high angle are found but generally poorly defined; both graded and reverse graded bedding noted; laterally beds of silt size grains are found as are red claystone and quartz cobble conglomerate; well indurated to friable; generally resistant, weathers to rounded masses; ledge former.
CV-7	2.5	ARKOSIC SANDSTONE; light greenish-gray (5G 8/1) fresh, moderate orange-pink (10R 7/4) weathered; coarse sand size grains of poorly sorted, angular quartz, pink and orange feldspar, granitic fragments, and mica flakes; thick bedded; medium-scale trough and tabular cosets of high angle cross-beds; well indurated to friable; weathers blocky; resistant.
CV-6	12.5	CLAYSTONE; bottom 1/2 gray red-purple (5RP 4/2) fresh, dusky grayish red-purple (5RP 3/2) weathered, top 1/2 is light olive gray (5Y 6/1) fresh, light brownish-gray (5YR 6/1) weathered; clay to silt size clasts; subangular, poorly sorted, coarse sand size grains in thin arkosic lenses noted, these arkosic lenses are identical in appearance, bedding stuctures, and composition to unit CV-5; a slope former with several resistant ledges.
CV-5	2.0	ARKOSIC SANDSTONE; light grayish orange-pink (10R 8/4) fresh, pale grayish reddish-brown (10R 4.5/3)

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		weathered; medium to coarse sand clasts of poorly sorted, angular quartz and pink and orange feldspar; medium to thickly-bedded; low to high angle tabular and trough cross-beds are poorly defined; laterally becomes finer-grained; well indurated to friable; weathers blocky; resistant, ledge former.
CV-4	29.0	CLAYSTONE; bottom 1/3 light olive gray (5Y 6/1) fresh, light green-gray (5GY 7/1) weathered, upper 2/3 is pale grayish-red (10R 5/2) fresh and weathered; clay to silt size clasts, silt clasts often with a pinkish coloration; contains interbedded lenses of arkosic sandstone, lenses are less than 1 foot in thickness, sand is coarse-grained, poorly sorted, angular, clasts of quartz and pink to orange feldspar; claystone is obscurely bedded; friable; slope former.
CV-3	5.0	CLAYSTONE; grayish red-purple (5RP 4/2) fresh and weathered; clay to silt size clasts; nodular, nodules are micritic and are up to 1/2 inch in longest dimension and decrease in abundance vertically, nodules are mottled very light gray (N 8) to pale purple (5P 6/2); bedding is obscured; friable; slope former.
CV-2	14.0	SUBAKOSIC SANDSTONE/SILTSTONE/ CLAYSTONE; moderate grayish-red (5R 5/2) fresh, grayish-brown (5YR 3/2) weathered; clay to medium sand size clasts of well sorted, subangular, quartz, and pink feldspar; lower 9 feet is mostly claystone with interbedded, color laminated, thin-bedded siltstone, some limy nodules are also found in this zone; the upper 5 feet is

APPENDIX A (continued)

Unit	Thickness (ft.)	Description
		dominantly a medium-grained sandstone with interbedded siltstone, the siltstone is very thinly-bedded to laminated and micaceous, the sandstone has local medium-scale, low angle, trough and tabular cross-beds which trend to the southeast, bedding is thin to medium, horizontal burrows from 0.25 inches to 2 inches in diameter are seen on the underside of silty beds which overlie claystones; weathering is flaggy to slabby; the unit as a whole is semi-resistant.
CV-1	1.0	CLAYSTONE; grayish-red (10R 4/2) fresh and weathered; clay to silt size clasts; micritic nodules up to 3 inches in long dimension are abundant, nodules are sparsely fossiliferous and contain brachiopod fragments; friable; weathers to a slope.
CV-0	0.0	Top of the Moya Formation; gradational, conformable contact.
Total	134.5	

APPENDIX B

CLASTIC POINT COUNT ANALYSIS

APPENDIX B

Verbal Summation

Nineteen thin sections were point counted (400 points/slide) primarily for determination of framework mineralogies. The purpose of these clastic analyses was to aid in provenance interpretation. Grain size is commonly restricted to medium sand for clastic analyses. But the error introduced by the use of clastic grains in all sand sizes and with some scatter outside of the sand range is minimal (Dickinson et al., 1983, p. 225). Restriction of clastic grain analyses to sand sized grains was adopted for this study.

The following descriptive text is a brief explanation of the data tables found in Appendix B.

Size, Sorting, and Rounding

Size, sorting, and roundness of clastic grains were determined from thin section. The average apparent diameter of measured grains was computed as a mean value. These values reflect random cross-sectional diameters and will be somewhat less than true values. The verbal sorting terms used are based on visual comparison with the charts of Pettijohn, Potter, and Siever (1972, p. 585). Verbal description of grain rounding reflects usage of visual estimation charts of Powers (1953, figure A-2, p. 118).

Size, sorting, and roundness determinations from thin section differ from, but are in general agreement with, hand sample analyses. General trends include increased sorting and angularity in rocks having smaller grain sizes.

Quartz

Quartz has been classified into monocrystalline and polycrystalline varieties for this study. Subdivision of monocrystalline quartz is based on extinction behavior (Folk, 1980, p. 72) into straight (< 1 degree rotation), slightly undulose (1 to 5 degrees rotation), and undulose (>5 degrees rotation) varieties. A trend toward undulose extinction in the larger grain sizes was noted, but these measurements were made on a flat stage and therefore may not reflect an accurate accounting of true extinction behavior.

Polycrystalline quartz in this study includes both composite and multicrystalline varieties. No subdivision of polycrystalline quartz was deemed necessary as the composite varieties (< 5 crystals per grain) vastly out numbered the multicrystalline varieties. Undulatory extinction behavior was also dominant in these crystals.

The presence of small vacuoles, hairlike inclusions, and microlites have been observed in all quartz varieties but are not common. Most varieties of quartz exhibited either sutured or anhedral, equant to subelongate grain outlines. Calcite replaced embayments indicate alteration.

APPENDIX B (continued)

Feldspar

Both potassium and plagioclase feldspar are present in most of the clastic thin sections analyzed. The abundance of potassium feldspar is in contrast to the paucity of plagioclase feldspar.

Potassium feldspars have a strong pink to orange color. The most common potassium feldspar variety recognized optically was orthoclase. The orthoclase is untwinned and commonly extensively altered to a dark colored, clay-like substance that merges with matrix material. Trace amounts of microcline, graphic intergrowths of microcline and quartz, and perthitic intergrowths of microcline and albite are also found in a few samples. The extensive alteration of feldspar grains, particularly microcline and perthite, makes recognition by optical means nearly impossible. Much of what is called orthoclase may well be altered microcline or perthite.

Plagioclase grains observed in thin section are invariably twinned. Albite twinning is more common than Carlsbad twinning and combined Carlsbad-Albite twinning is rare. Sericitization of plagioclase grains is the most common alteration process observed.

Micas

Biotite and muscovite occur in subequal but minor amounts in most of the samples. These micas are typically unaltered and are in a platy form. In hand sample the presence of mica flakes appears to be ubiquitous in the siltstones to fine grained sandstones.

Lithic Fragments

Fragments of plutonic igneous, metamorphic, and sedimentary origin were observed. Plutonic igneous lithic fragments have been identified as being exclusively granitic in composition. Fresh and weathered granitic fragments are composed of fine to coarsely crystalline quartz, pink to orange orthoclase, muscovite, and biotite. Although more common in the coarse sand sizes, trace amounts of granitic fragments are also found in the fine sand sizes.

Metamorphic lithic fragments of gneissic composition have been observed. Overlap of identification parameters between granitic and gneissic fragments may exist and some identification problems are present, particularly in altered grains. Fine grained metamorphic rock fragments are observed in hand sample, but not in thin section. This may be due to the alteration and rapid weathering of finely crystalline metamorphic fragments in the sand sizes.

APPENDIX B (continued)

In decreasing order of abundance sedimentary rock fragments include, carbonate, claystone, and sandstone. Carbonate rock fragments are locally derived and contain echinoderm spines, pelmatozoans, bryozoans, molluscs, brachiopods, and forams. These fragments are commonly well rounded and micritized. Shale clasts are typically light gray-green and rounded with a fine grained internal fabric. Sandstone fragments are typically fine grained with moderate to poorly sorted constituent grains.

Cements

Three cement mineralogies have been recognized in thin section. These cements, in order of decreasing abundance, are calcite, silica, and hematite. Calcite cement fills intergranular areas as a blocky mosaic or as syntaxial overgrowths. Silica cement occurs more commonly as overgrowths cementing grains together. Hematite cement is ubiquitous as a grain coating, in most samples, but is a minor volumetric constituent. Early void filling cements are often obscured by later alteration products.

Matrix

Matrix classification used herein is that of Dickinson (1970). In decreasing order of abundance, matrix is identified as epimatrix (i.e. from alteration of orthoclase feldspar), orthomatrix, and pseudomatrix. Epimatrix accounts for most of the matrix material and is recognized obscuring cement textures.

Opaque and Heavy Minerals

Ferromagnesian minerals constitute the bulk of this grouping. Alteration products of ferromagnesian minerals create dark to opaque patches in some samples. Alteration products of ferromagnesian minerals also contribute to matrix material. Other heavy minerals are extremely rare, or not identified.

Porosity

Most primary porosity has been obscured by alteration of framework grains to matrix material. Some minor secondary porosity has been created by feldspar dissolution. Little porosity was recognized especially in the finer grained samples.

APPENDIX B (continued)

Unidentified

This grouping contains unknowns along with other rare grain types not listed. The alteration of feldspars and ferromagnesian minerals in particular creates grains which cannot be positively identified.

APPENDIX B (continued)

Sample Number	CC-2	CC-4	CC-14	CC-18	CU-3	CU-7
Ave. App. Diameter(mm):	0.22	0.37	0.05	0.06	0.08	0.39
Sorting:	well	well	well	well	well	well
Roundness:	ang.	ang.	ang.	ang.	s.r.	rnd.
			Percentage			
Quartz:	50.8	65.2	55.5	60.5	59.3	33.3
Mx(straight)	1.0	1.8	51.1	57.3	37.1	8.7
Mx(sl. und.)	13.8	15.2	4.4	3.2	18.5	10.1
Mx(undulose)	35.9	45.0	tr	tr	3.7	11.6
Px(comp. and multi.)	tr	5.0	0.0	0.0	0.0	2.9
K-spar:	26.0	27.4	1.0	7.0	11.4	3.3
Orthoclase	26.0	27.4	1.0	7.0	11.4	3.3
Microcline	tr	tr	0.0	tr	0.0	0.0
Perthite	tr	tr	0.0	tr	0.0	0.0
Plagioclase:	0.9	tr	tr	1.0	0.0	1.0
Untwinned	0.0	0.0	0.0	0.0	0.0	0.0
A-twin	0.9	tr	tr	1.0	0.0	1.0
C-twin	tr	0.0	0.0	0.0	0.0	0.0
Micas:	2.3	0.6	0.7	0.3	1.6	0.0
Biotite	1.7	0.0	0.0	0.0	0.8	0.0
Muscovite	0.6	0.6	0.7	0.3	0.8	0.0
Lithics:	tr	0.0	0.0	0.0	0.0	16.9
IRF (Granite)	tr	0.0	0.0	0.0	0.0	0.0
MRF (Gneiss)	tr	0.0	0.0	0.0	0.0	0.0
SRF Sandstone	0.0	0.0	0.0	0.0	0.0	0.0
Shale	0.0	0.0	0.0	0.0	0.0	0.0
Carbonate	0.0	0.0	0.0	0.0	0.0	16.9
Cement:	2.0	1.0	tr	2.8	2.4	1.0
Silica	2.0	1.0	tr	0.0	0.0	1.0
Calcite	tr	0.0	0.0	2.8	2.4	0.0
Hematite	tr	tr	tr	0.0	0.0	tr
Matrix:	9.0	3.6	33.6	16.9	15.2	3.6
Orthomatrix	4.2	tr	5.6	8.5	3.1	tr
Epimatrix	4.2	3.6	28.0	8.4	12.1	3.6
Pseudomatrix	0.6	0.0	0.0	0.0	tr	0.0
Opaques and Heavy Min.:	7.8	2.2	8.2	10.8	10.1	2.2
Porosity:	0.0	tr	0.0	0.0	0.0	0.0
Unidentified:	0.6	tr	tr	0.3	tr	0.6

tr = trace occurrence; observed but not point counted.

APPENDIX B (continued)

Sample Number	CU-8	CU-23	CU-27	DC-3	DC-12	DC-16
Ave. App. Diameter(mm):	0.15	2.0	0.05	0.11	0.10	1.0
Sorting:	well	well	well	well	well	poor
Roundness:	rnd.	rnd.	s.r.	s.r.	rnd.	s.r.
			Percentage			
Quartz:	19.0	5.9	56.3	60.5	51.8	60.4
Mx(straight)	5.1	0.0	5.4	0.0	1.6	0.0
Mx(sl. und.)	10.4	0.6	18.8	8.1	22.7	0.0
Mx(undulose)	3.5	5.1	32.1	40.3	27.5	2.1
Px(comp. and multi.)	0.0	0.2	0.0	12.1	0.0	58.3
K-spar:	0.9	0.0	26.0	13.5	22.1	9.9
Orthoclase	0.9	0.0	26.0	13.1	22.1	9.9
Microcline	0.0	0.0	0.0	0.4	0.0	0.0
Perthite	0.0	0.0	0.0	0.0	0.0	0.0
Plagioclase:	0.4	0.0	0.0	1.1	0.5	0.2
Untwinned	0.0	0.0	0.0	tr	0.0	0.0
A-twin	0.4	0.0	0.0	0.2	0.5	0.2
C-twin	0.0	0.0	0.0	0.9	0.0	0.0
Micas:	0.4	0.0	0.6	1.4	0.0	0.0
Biotite	0.0	0.0	0.6	1.4	0.0	0.0
Muscovite	0.4	0.0	0.0	0.0	0.0	0.0
Lithics:	31.5	58.9	0.0	0.0	0.0	2.0
IRF (Granite)	0.0	0.0	0.0	0.0	0.0	2.0
MRF (Gneiss)	0.0	0.0	0.0	0.0	0.0	0.0
SRF Sandstone	0.0	0.0	0.0	0.0	0.0	0.0
Shale	0.0	0.0	tr	0.0	0.0	0.0
Carbonate	31.5	58.9	0.0	0.0	0.0	2.0
Cement:	1.3	tr	0.6	9.4	tr	2.2
Silica	0.0	0.0	0.0	0.0	0.0	0.0
Calcite	1.3	tr	0.0	9.4	tr	0.0
Hematite	0.0	0.0	0.6	0.0	0.0	tr
Matrix:	44.8	33.4	11.0	7.8	14.4	24.8
Orthomatrix	3.9	33.4	3.0	tr	tr	3.5
Epimatrix	40.9	0.0	8.0	7.7	14.4	21.3
Pseudomatrix	0.0	0.0	0.0	tr	tr	0.0
Opaques and Heavy Min.:	1.7	0.0	5.5	6.0	11.0	0.5
Porosity:	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified:	0.0	tr	0.0	0.3	0.2	0.1

tr = trace occurrence; observed but not point counted.

APPENDIX B (continued)

Sample Number	AT-2	AT-7	AT-8	AT-9A	CV-2	CV-5A
Ave. App. Diameter(mm):	0.2	0.6	1.8	>2.0	0.2	2.0
Sorting:	well	mod.	poor	v.p.	mod.	v.p.
Roundness:	s.a.	ang.	ang.	rnd.	s.a.	s.a.
				Percentage		
Quartz:	59.4	51.4	77.2	17.5	46.7	53.2
Mx(straight)	0.0	0.0	0.0	tr	10.0	5.2
Mx(sl. und.)	16.8	6.7	4.5	4.9	16.7	17.0
Mx(undulose)	33.2	18.4	28.7	12.3	20.0	30.1
Px(comp. and multi.)	9.4	26.3	44.0	0.4	0.0	0.0
K-spar:	29.9	16.0	8.3	4.9	10.7	24.7
Orthoclase	29.9	16.0	8.3	4.9	10.7	24.7
Microcline	0.0	0.0	0.0	0.0	0.0	tr
Perthite	0.0	0.0	0.0	0.0	0.0	tr
Plagioclase:	0.3	tr	0.3	0.0	0.4	0.0
Untwinned	0.0	0.0	0.0	0.0	0.0	0.0
A-twin	0.3	tr	0.3	0.0	0.4	0.0
C-twin	0.0	0.0	0.0	0.0	0.0	0.0
Micas:	0.3	tr	0.0	0.0	0.4	0.3
Biotite	0.3	0.0	0.0	0.0	0.0	0.0
Muscovite	0.0	tr	0.0	0.0	0.4	0.3
Lithics:	0.0	4.0	1.1	56.5	0.0	10.3
IRF (Granite)	0.0	4.0	1.1	0.0	0.0	10.3
MRF (Gneiss)	0.0	0.0	0.0	0.0	0.0	tr
SRF Sandstone	0.0	0.0	0.0	0.2	0.0	0.0
Shale	0.0	0.0	0.0	0.2	0.0	0.0
Carbonate	0.0	0.0	0.0	56.1	0.0	0.0
Cement:	0.0	0.0	0.0	5.3	2.9	0.6
Silica	0.0	0.0	0.0	0.0	0.0	0.6
Calcite	0.0	0.0	0.0	5.3	2.9	0.0
Hematite	0.0	0.0	0.0	0.0	0.0	0.0
Matrix:	8.0	25.9	6.5	14.2	13.2	10.9
Orthomatrix	1.5	25.9	5.1	14.2	2.2	3.6
Epimatrix	6.5	tr	1.4	0.0	6.6	7.3
Pseudomatrix	tr	0.0	0.0	0.0	2.2	tr
Opaques and Heavy Min.:	2.1	2.7	6.8	0.0	25.7	0.9
Porosity:	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified:	0.0	0.0	0.0	1.0	0.0	0.0

tr = trace occurrence; observed but not point counted.

APPENDIX B (continued)

Sample Number	CV-5B	------	------	------	------
Ave. App. Diameter(mm):	1.0	------	------	------	------
Sorting:	v.p.	------	------	------	------
Roundness:	s.a.	------	------	------	------
			Percentage		
Quartz:	43.7	------	------	------	------
Mx(straight)	0.0	------	------	------	------
Mx(sl. und.)	0.0	------	------	------	------
Mx(undulose)	5.2	------	------	------	------
Px(comp. and multi.)	38.5	------	------	------	------
K-spar:	19.5	------	------	------	------
Orthoclase	19.5	------	------	------	------
Microcline	0.0	------	------	------	------
Perthite	0.0	------	------	------	------
Plagioclase:	1.1	------	------	------	------
Untwinned	tr	------	------	------	------
A-twin	1.1	------	------	------	------
C-twin	0.0	------	------	------	------
Micas	0.5	------	------	------	------
Biotite	0.0	------	------	------	------
Muscovite	0.5	------	------	------	------
Lithics:	2.5	------	------	------	------
IRF (Granite)	2.5	------	------	------	------
MRF (Gneiss)	tr	------	------	------	------
SRF Sandstone	0.0	------	------	------	------
Shale	0.0	------	------	------	------
Carbonate	0.0	------	------	------	------
Cement:	tr	------	------	------	------
Silica	tr	------	------	------	------
Calcite	tr	------	------	------	------
Hematite	0.0	------	------	------	------
Matrix:	32.4	------	------	------	------
Orthomatrix	3.2	------	------	------	------
Epimatrix	29.2	------	------	------	------
Pseudomatrix	0.0	------	------	------	------
Opaques and Heavy Min.:	0.2	------	------	------	------
Porosity:	0.0	------	------	------	------
Unidentified:	0.0	------	------	------	------

tr = trace occurrence; observed but not point counted.

APPENDIX C

CARBONATE POINT COUNT ANALYSES

APPENDIX C

Verbal Summation

Thirty six carbonate thin sections were point counted (400 counts/slide) for the volumetric determination of mineralogy, abundance, and diversity of carbonate grain constituents. All thin sections were cut perpendicular to bedding planes to maintain a consistent orientation. Alizarin Red S and potassium ferricyanide were used as staining reagents to differentiate calcite, dolomite, and siderite mineralogies.

Data sheets in Appendix C are divided into skeletal and non-skeletal constituents. The following text elaborates on this data.

Skeletal Constituents

Grains of skeletal origin are recognized and identified by features characteristic to each grain type. These features are not discussed herein. Grain types recognized from thin section include crinoid columnals and other pelmatozoan parts, echinoid spines and plates, digitate, encrusting, and fenestrate bryozoans, punctate, pseudopunctate, and impunctate brachiopods, brachiopod spines, phylloid, coralline, and encrusting algae, rugose corals and indeterminate corals, pelecypod and gastropod molluscs, fusulinid and uniserial forams, calcisponge spicules, trilobites, ostracods, fish bones, scales, and teeth, and other vertebrate remains.

Non-skeletal Constituents

This grouping consists of grains, matrix, cement, and mineralogies that are not attributable to skeletal origin.

<u>Intraclasts:</u> Intraclasts as used herein are clasts of intrabasinal origin, that usually exhibit soft sediment deformation. The intraformational distinction was made in the field and in thin section analyses. Many units of lithified, rounded, reworked limestone clasts exist in the study area, but most of these are identified as carbonate lithic fragments and are considered clastics. Nodular limestone units may be the product of intrabasinal reworking.

<u>Peloids:</u> Peloids as used herein are micrite or micritized grains in which there is no internal structure. Peloids may have had a fecal skeletal origin but cannot be recognized as such. Rounded limestone clasts of intrabasinal or extrabasinal origin may have been micritized to form peloids.

<u>Micrite:</u> Micrite as herein is assumed to be a diagenetic product of carbonate mud. Recognition is based on the presence of equant crystals of low magnesium calcite which are less than 5 microns in diameter. Micrite is the dominant constituent in most samples from this study.

APPENDIX C (continued)

Neospar: Neospar is the term used herein for the diagenetic alteration product of micrite. Neospar is composed of equant crystals of low magnesian calcite. Subdivision of neospar is based on crystal size, varieties are microspar (5 to 20 microns in diameter) and pseudospar (> 20 microns in diameter). Neospar is common in most samples.
Spar: Spar as used herein is chemically precipitated carbonate cement in intragranular and intergranuler pores. Spar, which is composed of low magnesiam calcite, is recognized by crystal clarity, crystal size (> 30 microns), and crystal habit. Spar takes the form of blocky or drusy crystals in pore space or syntaxial overgrowths. Overgrowths on pelmatozoan hardparts are common.
Clastic Debris: This group includes extrabasinal grains. These grains are most commonly sand sized quartz or pink feldspar , but occasionally are rounded clasts of limestone. Clay size clasts while often present in noticeable amounts are difficult to evaluate volumetrically due to point counting procedures. Clastic debris is commonly abundant.
Dolomite: Determination of dolomite mineralogy is based on Alizarin Red S staining reagent. Dolomite in samples studied is most commonly microcrystalline and forms a micritic texture but also occurs as fracture fillings and skeletal replacements. Dolomite which is not of secondary origin (fracture fills and skeletal grain replacements) consists of equant, sometimes rhombohedral, crystals less than .01 mm in diameter and may represent a primary mineralogy.
Silica: Silica is ubiquitous in occurrence and is a secondary filling of fractures and pores or replaces skeletal grains. Jasper replacement of skeletal grains is a common feature. Accumulation of jasper in thin horizontal beds is seen locally.
Phosphate: Phosphate is in the form of collophane and is seen as a replacement of fossil fragments and filling voids with structureless to fibrous mineral.
Pore Space: Original pore space that has not been secondarily filled is a very small percentage in these samples. Intragranular pores are filled with drusy spar. Intergranular pores are filled with micrite matrix. A small amount of moldic porosity was noted.
Opaque Materials: These materials are either from the alteration of ferromagnesian minerals or are of organic origin. Although volumetrically insignificant, petroliferous and carbonaceous blebs, stringers, and amorphous masses are found in most samples.
Unidentified: This group includes unidentified grains of skeletal and non-skeletal origin.

APPENDIX C (continued)

Sample Number:	CC-0	CC-1	CC-9A	CC-9B	CC-9C	CC-9D
			Percentage			
Echinoderms (total):	70.0	5.0	19.3	3.5	1.5	3.1
Pelmatozoans	69.2	4.8	19.3	3.5	1.5	3.1
Bryozoans (total):	0.3	tr	0.2	1.2	0.7	0.4
Digitate	0.3	tr	0.2	1.2	0.7	0.4
Encrusting	0.0	0.0	0.0	0.0	0.0	0.0
Brachiopods (total):	1.8	0.9	0.7	2.8	2.0	1.1
Punctate	0.2	0.7	0.5	2.1	0.0	0.0
Pseudopunctate	1.4	0.0	0.2	0.0	0.9	0.0
Impunctate	0.0	0.2	0.0	0.0	1.1	0.9
Spines	0.2	0.0	0.0	0.7	0.0	0.2
Algae (total):	0.0	0.0	0.0	0.0	0.0	0.0
Phylloid	0.0	0.0	0.0	0.0	0.0	0.0
Coralline	0.0	0.0	0.0	0.0	0.0	0.0
Encrusting	0.0	0.0	0.0	0.0	0.0	0.0
Coral (total):	0.0	0.0	0.0	0.0	0.0	2.2
Rugose	0.0	0.0	0.0	0.0	0.0	2.2
Molluscs (total):	0.7	0.5	0.7	0.7	0.8	1.1
Pelecypods	0.7	0.5	0.7	0.7	0.8	1.1
Gastropods	0.0	0.0	0.0	0.0	0.0	0.0
Foraminifers (total):	0.4	2.7	7.8	0.0	0.0	19.3
Fusulinids	0.4	2.7	7.8	0.0	0.0	19.3
Uniserial	0.0	0.0	0.0	0.0	0.0	0.0
Spicules (Calcispongia):	0.0	0.0	0.0	0.0	0.0	0.2
Trilobites:	0.6	tr	0.2	0.7	0.2	0.4
Ostracods:	0.2	tr	0.2	0.2	0.7	0.4
Vertebrate Remains:	0.0	0.0	0.0	0.0	0.0	0.0
Intraclasts:	0.0	0.0	0.0	0.0	0.0	0.0
Peloids:	0.0	0.0	0.0	0.0	0.0	0.0
Micrite:	3.4	73.7	44.5	57.1	60.5	42.2
Neospar:	10.0	3.0	16.9	2.3	8.7	14.2
Spar:	10.0	11.2	6.0	28.6	7.2	11.2
Clastic Debris (total):	0.0	0.0	0.0	0.0	0.0	0.0
Quartz	0.0	0.0	0.0	0.0	0.0	0.0
Dolomite:	0.0	0.0	0.0	0.0	0.0	0.0
Silica:	0.7	0.2	0.5	0.5	2.2	0.7
Phosphate:	0.0	0.0	0.0	0.0	0.0	0.0
Pore Space:	0.0	1.1	0.0	0.0	0.0	0.0
Opaque Material (total):	0.0	0.5	0.5	tr	1.7	1.1
Organics	0.0	tr	tr	tr	tr	tr
Unidentified:	1.9	1.2	2.5	2.4	1.7	2.1

tr = trace occurrence; observed but not point counted.

APPENDIX C (continued)

Sample Number:	CC-19A	CC-19B	CC-20	CC-22A	CC-22B
			Percentage		
Echinoderms (total):	0.2	0.7	1.9	0.0	2.3
Pelmatozoans	0.2	0.7	1.9	0.0	2.3
Bryozoans (total):	0.0	0.0	0.0	tr	0.0
Digitate	0.0	0.0	0.0	tr	0.0
Encrusting	0.0	0.0	0.0	0.0	0.0
Brachiopods (total):	0.9	2.7	0.3	1.3	1.8
Punctate	0.0	0.0	0.0	0.0	0.0
Pseudopunctate	0.0	0.0	0.0	0.0	0.0
Impunctate	0.9	2.7	0.3	1.3	1.8
Spines	0.0	0.0	0.0	0.0	0.0
Algae (total):	0.0	0.7	0.0	0.0	10.5
Phylloid	0.0	0.0	0.0	0.0	0.0
Coralline	0.0	0.0	0.0	0.0	0.0
Encrusting	0.0	0.7	0.0	0.0	10.5
Coral (total):	0.0	0.0	0.0	0.0	0.0
Rugose	0.0	0.0	0.0	0.0	0.0
Molluscs (total):	14.1	3.6	7.7	4.3	19.8
Pelecypods	10.6	2.7	6.6	4.3	13.8
Gastropods	3.5	0.9	1.1	0.0	6.0
Foraminifers (total):	0.5	tr	tr	0.0	0.0
Fusulinids	0.5	tr	tr	0.0	0.0
Uniserial	0.0	0.0	0.0	0.0	0.0
Spicules (Calcispongia):	0.0	0.0	0.0	0.0	0.0
Trilobites:	0.0	0.0	0.0	0.0	0.0
Ostracods:	1.4	1.1	0.5	1.1	0.0
Vertebrate Remains:	0.0	0.0	0.0	0.0	0.0
Intraclasts:	0.0	0.0	0.0	0.0	6.4
Peloids:	0.0	0.0	0.0	0.0	0.0
Micrite:	69.8	56.4	35.5	43.5	3.8
Neospar:	5.1	8.0	28.6	0.0	1.8
Spar:	3.0	22.3	22.0	15.1	21.3
Clastic Debris (total):	0.5	1.1	0.8	27.1	18.0
Quartz	0.5	1.1	0.8	27.1	18.0
Dolomite:	0.0	0.0	0.0	0.0	0.0
Silica:	1.2	1.4	0.0	0.0	0.0
Phosphate:	0.0	0.0	0.0	0.0	0.0
Pore Space:	0.0	0.0	0.0	0.0	0.0
Opaque Material (total):	0.5	1.1	tr	7.3	11.5
Organics	tr	tr	tr	tr	1.2
Unidentified:	2.8	0.9	2.7	0.3	2.8

tr = trace occurrence; observed but not point counted.

APPENDIX C (continued)

Sample Number:	CC-25	CC-26	CU-0	CU-5	CU-9	CU-10
	Percentage					
Echinoderms (total):	0.0	1.4	54.8	2.8	0.8	19.9
Pelmatozoans	0.0	1.4	53.9	2.8	0.8	19.7
Bryozoans (total):	0.0	0.0	0.7	0.4	tr	tr
Digitate	0.0	0.0	0.7	0.4	0.0	0.0
Encrusting	0.0	0.0	0.0	0.0	tr	tr
Brachiopods (total):	0.0	1.4	2.6	0.9	1.6	3.3
Punctate	0.0	0.0	0.7	0.0	1.6	3.3
Pseudopunctate	0.0	0.0	0.0	0.5	0.0	0.0
Impunctate	0.0	1.4	1.9	0.4	0.0	0.0
Spines	0.0	0.0	0.0	0.0	0.0	0.0
Algae (total):	0.0	0.0	0.0	0.0	0.0	0.0
Phylloid	0.0	0.0	0.0	0.0	0.0	0.0
Coralline	0.0	0.0	0.0	0.0	0.0	0.0
Encrusting	0.0	0.0	0.0	0.0	0.0	0.0
Coral (total):	0.0	0.0	0.0	0.0	0.0	0.0
Rugose	0.0	0.0	0.0	0.0	0.0	0.0
Molluscs (total):	0.0	10.1	0.5	3.7	0.2	tr
Pelecypods	0.0	10.1	0.5	2.8	0.2	tr
Gastropods	0.0	0.0	0.0	0.9	0.0	tr
Foraminifers (total):	0.0	0.0	0.0	15.6	tr	0.0
Fusulinids	0.0	0.0	0.0	15.6	tr	0.0
Uniserial	0.0	0.0	0.0	0.0	0.0	0.0
Spicules (Calcispongia):	0.0	0.0	0.0	0.0	0.0	0.0
Trilobites:	0.0	0.0	0.0	0.4	tr	tr
Ostracods:	0.0	0.5	0.2	tr	0.4	tr
Vertebrate Remains:	0.0	0.0	0.0	0.0	0.0	0.0
Intraclasts:	0.0	5.3	0.0	0.0	0.0	0.0
Peloids:	0.0	0.0	0.0	0.2	0.0	0.0
Micrite:	90.3	51.4	31.0	51.2	88.5	75.2
Neospar:	0.0	6.7	0.0	6.4	3.3	0.0
Spar:	0.0	3.9	2.4	16.0	2.7	1.4
Clastic Debris (total):	9.3	3.9	0.0	tr	0.4	0.0
Quartz	9.3	3.9	0.0	tr	0.4	0.0
Dolomite:	0.0	0.0	0.0	0.0	0.0	0.0
Silica:	0.0	0.0	0.0	0.0	tr	tr
Phosphate:	0.0	5.8	0.0	0.0	0.0	0.0
Pore Space:	0.0	0.0	2.6	0.0	0.0	0.0
Opaque Material (total):	0.4	5.3	3.5	0.4	1.6	0.2
Organics	tr	1.3	1.1	tr	tr	tr
Unidentified:	0.0	4.4	1.7	2.0	0.2	0.0

tr = trace occurrence; observed but not point counted.

APPENDIX C (continued)

Sample Number:	CU-11	CU-12	CU-13A	CU-13B	CU-14A
			Percentage		
Echinoderms (total):	0.0	0.2	0.0	0.0	0.0
Pelmatozoans	0.0	0.2	0.0	0.0	0.0
Bryozoans (total):	0.0	0.0	0.0	0.0	0.0
Digitate	0.0	0.0	0.0	0.0	0.0
Encrusting	0.0	0.0	0.0	0.0	0.0
Brachiopods (total):	0.0	0.2	0.0	0.0	0.2
Punctate	0.0	0.2	0.0	0.0	0.2
Pseudopunctate	0.0	0.0	0.0	0.0	0.0
Impunctate	0.0	0.0	0.0	0.0	0.0
Spines	0.0	0.0	0.0	0.0	0.0
Algae (total):	0.0	0.0	0.0	0.0	0.0
Phylloid	0.0	0.0	0.0	0.0	0.0
Coralline	0.0	0.0	0.0	0.0	0.0
Encrusting	0.0	0.0	0.0	0.0	0.0
Coral (total):	0.0	0.0	0.0	0.0	0.0
Rugose	0.0	0.0	0.0	0.0	0.0
Molluscs (total):	0.0	0.0	0.0	0.2	0.9
Pelecypods	0.0	0.0	0.0	0.0	0.0
Gastropods	0.0	0.0	0.0	0.2	0.9
Foraminifers (total):	0.0	tr	0.0	0.5	1.9
Fusulinids	0.0	tr	0.0	0.5	1.9
Uniserial	0.0	0.0	0.0	0.0	0.0
Spicules (Calcispongia):	0.0	0.0	0.0	0.0	0.0
Trilobites:	0.0	0.0	0.0	0.0	0.0
Ostracods:	tr	0.4	0.0	0.0	tr
Vertebrate Remains:	0.0	0.0	0.0	0.0	0.0
Intraclasts:	0.0	0.0	0.0	0.0	0.0
Peloids:	0.0	0.0	0.0	0.0	0.0
Micrite:	tr	28.2	96.6	97.0	80.2
Neospar:	20.8	3.4	1.2	1.1	tr
Spar:	5.4	0.5	0.0	0.0	5.1
Clastic Debris (total):	0.0	tr	tr	0.0	tr
Quartz	0.0	tr	tr	0.0	tr
Dolomite:	70.9	67.1	1.1	1.1	9.4
Silica:	2.3	0.0	1.1	0.0	2.3
Phosphate:	0.0	0.0	0.0	0.0	0.0
Pore Space:	0.0	0.0	0.0	tr	0.0
Opaque Material (total):	0.6	tr	tr	0.2	tr
Organics	0.4	tr	tr	tr	tr
Unidentified:	0.0	0.0	0.0	0.0	0.0

tr = trace occurrence; observed but not point counted.

APPENDIX C (continued)

Sample Number:	CU-14B	CU-15A	CU-15B	CU-29	CU-39
	Percentage				
Echinoderms (total):	3.2	4.1	2.0	0.8	0.0
Pelmatozoans	3.2	4.1	2.0	0.8	0.0
Bryozoans (total):	3.9	2.3	2.3	1.3	0.0
Digitate	3.9	2.3	2.3	1.3	0.0
Encrusting	0.0	0.0	0.0	0.0	0.0
Brachiopods (total):	1.0	0.5	0.8	0.0	1.0
Punctate	1.0	0.5	0.7	0.0	1.0
Pseudopunctate	0.0	0.0	0.1	0.0	0.0
Impunctate	0.0	0.0	0.0	0.0	0.0
Spines	0.0	0.0	0.0	0.0	0.0
Algae (total):	0.0	1.1	0.0	0.0	0.0
Phylloid	0.0	0.0	0.0	0.0	0.0
Coralline	0.0	0.2	0.0	0.0	0.0
Encrusting	0.0	0.9	0.0	0.0	0.0
Coral (total):	0.0	0.0	0.0	0.0	0.0
Rugose	0.0	0.0	0.0	0.0	0.0
Molluscs (total):	2.9	8.7	tr	0.0	4.5
Pelecypods	2.2	7.3	0.0	0.0	2.6
Gastropods	0.7	1.4	0.0	0.0	1.9
Foraminifers (total):	0.7	1.1	0.0	0.0	0.0
Fusulinids	0.7	1.1	0.0	0.0	0.0
Uniserial	0.0	0.0	0.0	0.0	0.0
Spicules (Calcispongia):	0.0	0.0	0.0	0.0	0.0
Trilobites:	0.5	tr	0.1	0.0	0.0
Ostracods:	0.5	0.2	0.1	tr	0.3
Vertebrate Remains:	0.0	0.0	0.1	0.0	0.0
Intraclasts:	0.0	0.0	0.0	0.0	0.0
Peloids:	2.0	7.7	0.0	0.0	0.0
Micrite:	54.5	42.3	64.9	tr	61.7
Neospar:	8.3	10.7	21.8	95.6	20.0
Spar:	12.4	18.7	4.8	0.0	9.3
Clastic Debris (total):	tr	tr	0.1	2.3	tr
Quartz	tr	tr	0.1	2.3	tr
Dolomite:	7.8	0.0	2.1	0.0	0.0
Silica:	2.3	0.0	0.5	0.0	2.4
Phosphate:	0.0	0.0	0.0	0.0	0.0
Pore Space:	0.0	0.0	0.0	0.0	0.0
Opaque Material (total):	tr	0.2	0.1	0.0	0.8
Organics	tr	tr	tr	0.0	tr
Unidentified:	0.0	2.2	0.3	0.0	0.0

tr = trace occurrence; observed but not point counted.

APPENDIX C (continued)

Sample Number:	DC-5A	DC-13	DC-15	AT-4	AT-12
			Percentage		
Echinoderms (total):	2.3	2.1	0.2	3.4	0.7
Pelmatozoans	2.3	2.1	0.2	3.4	0.7
Bryozoans (total):	3.0	3.8	0.0	1.7	0.0
Digitate	3.0	3.6	0.0	1.7	0.0
Encrusting	0.0	0.2	0.0	0.0	0.0
Brachiopods (total):	4.4	1.5	0.0	0.3	0.0
Punctate	0.0	0.0	0.0	0.0	0.0
Pseudopunctate	0.0	0.0	0.0	0.0	0.0
Impunctate	4.4	1.5	0.0	0.0	0.0
Spines	0.0	0.0	0.0	0.0	0.0
Algae (total):	4.4	0.0	0.0	1.2	0.0
Phylloid	0.0	0.0	0.0	0.0	0.0
Coralline	0.0	0.0	0.0	0.0	0.0
Encrusting	4.4	0.0	0.0	1.2	0.0
Coral (total):	0.0	0.0	0.0	0.0	0.0
Rugose	0.0	0.0	0.0	0.0	0.0
Molluscs (total):	8.7	3.6	0.2	1.4	0.9
Pelecypods	8.7	3.6	0.2	1.4	0.7
Gastropods	0.0	0.0	0.0	0.0	0.2
Foraminifers (total):	8.7	0.2	tr	19.2	0.0
Fusulinids	8.7	0.0	0.0	19.2	0.0
Uniserial	0.0	0.2	tr	0.0	0.0
Spicules (Calcispongia):	0.0	0.0	0.0	0.0	0.0
Trilobites:	0.0	1.5	0.0	0.2	0.0
Ostracods:	0.3	0.6	tr	0.0	tr
Vertebrate Remains:	0.0	0.0	0.0	0.0	0.0
Intraclasts:	0.0	0.0	0.0	0.0	0.0
Peloids:	0.0	0.0	0.0	0.8	0.0
Micrite:	32.9	64.0	0.0	11.6	68.4
Neospar:	0.0	tr	88.3	31.4	0.9
Spar:	31.5	3.6	0.0	26.0	7.5
Clastic Debris (total):	0.0	tr	8.6	0.0	0.0
Quartz	0.0	tr	8.6	0.0	0.0
Dolomite:	0.0	1.1	0.3	0.0	0.2
Silica:	0.7	0.0	0.7	0.0	16.2
Phosphate:	0.0	0.0	0.0	0.0	0.0
Pore Space:	0.0	0.0	0.0	0.0	0.0
Opaque Material (total):	0.0	0.4	1.5	2.6	0.0
Organics	0.0	tr	0.7	1.9	0.0
Unidentified:	3.1	17.5	0.2	0.2	5.0

tr = trace occurrence; observed but not point counted.

APPENDIX C (continued)

Sample Number:	AT-20	CV-0	CV-9	CV-10
		Percentage		
Echinoderms (total):	1.5	5.1	1.7	4.8
Pelmatozoans	1.5	5.1	1.7	4.8
Bryozoans (total):	0.5	33.8	0.0	0.3
Digitate	0.5	33.8	0.0	0.3
Encrusting	0.0	0.0	0.0	0.0
Brachiopods (total):	0.5	0.6	1.4	0.3
Punctate	0.0	0.0	0.0	0.0
Pseudopunctate	0.0	0.0	0.0	0.0
Impunctate	0.5	0.6	1.4	0.3
Spines	0.0	0.0	0.0	0.0
Algae (total):	0.0	0.7	0.0	0.0
Phylloid	0.0	0.5	0.0	0.0
Coralline	0.0	0.0	0.0	0.0
Encrusting	0.0	0.0	0.0	0.0
Coral (total):	0.0	0.5	0.0	0.0
Rugose	0.0	0.0	0.0	0.0
Molluscs (total):	13.1	0.6	0.2	0.0
Pelecypods	11.9	0.3	0.2	0.0
Gastropods	1.2	0.3	0.0	0.0
Foraminifers (total):	0.2	tr	0.0	9.3
Fusulinids	0.0	0.0	0.0	9.3
Uniserial	0.2	tr	0.0	0.0
Spicules (Calcispongia):	0.0	0.0	0.0	0.0
Trilobites:	0.0	0.2	0.0	tr
Ostracods:	0.5	0.2	0.0	0.7
Vertebrate Remains:	0.0	0.0	0.0	0.0
Intraclasts:	0.0	0.0	0.0	0.0
Peloids:	1.5	1.1	0.0	0.0
Micrite:	9.4	30.2	14.9	29.4
Neospar:	0.0	5.6	46.7	38.7
Spar:	49.7	19.8	21.8	14.8
Clastic Debris (total):	3.2	0.0	11.8	tr
Quartz	3.0	0.0	11.8	tr
Dolomite:	1.0	0.0	0.0	0.0
Silica:	tr	0.0	0.0	0.0
Phosphate:	0.0	0.0	0.0	0.0
Pore Space:	0.0	0.0	0.2	0.0
Opaque Material (total):	5.0	0.0	1.1	1.3
Organics	4.1	0.0	0.9	1.1
Unidentified:	12.4	1.6	0.2	0.4

tr = trace occurrence; observed but not point counted.

APPENDIX D

QUALITATIVE THIN SECTION DESCRIPTIONS

APPENDIX D

Sample Number	Description
CC-14-2	Sandy, silty, laminated, reddish-brown siltstone.
CC-16-1 CC-16-2 CC-16-3	Algae encrusted shells of gastropods and pelecypods. Algae are in columnar laminated masses which encrust the host shell. Algal laminae entrap fragments of other molluscs and clastic debris. Host shell is often bored.
CC-18-A CC-18-B	Sandy, silty, laminated, brown, siltstone.
CC-26-1A CC-26-2B	Molluscan Biomicrite/Carbonate Wackestone; contains mollusc, brachiopod, and echinoid fossil remains. See duplicate slide (CC-26) in Appendix C.
CU-10-2	Pelmatozoan Biomicrite/Pelmatozoan Wackestone; contains pelmatozoan parts in a mud matrix. See duplicate slide (CU-10) in Appendix C.
CU-14-1A	Sparsely Fossiliferous Micrite/Mudstone; minor amounts of dolomite and silica in mud matrix, see slide (CU-14-A and CU-14-B) in Appendix C.
CU-41-2	Calclithite; coarse to very coarse sand size clasts of rounded limestone with sparry intergranular cement.
DC-5A-2	Fusulinid Biosparite/Fusulinid Packestone; fusulinids and other skeletal grains with sparry intergranular cement. See duplicate slide (DC-5A) in Appendix C.
DC-18-A DC-18-B	Calclithite; very coarse sand to granule size clasts of rounded limestone, quartz, orthoclase feldspar, and granite with a sparry cement.
DC-21-A DC-21-B	Calclithite; granule to pebble size clasts of rounded limestone with a sparry cement.
AT-7-2 AT-7-3	Arkosic Wacke; coarse sand to pebble size clasts of unweathered quartz, orthoclase feldspar, and granite in a paste-like

APPENDIX D (continued)

Sample Number	Description
	matrix of green silt to clay. See duplicate slide (AT-7-1) in Appendix B.
AT-8A	Subarkose; coarse sand to granule size grains of quartz, orthoclase feldspar, plagioclase feldspar, and granite. See duplicate slide (AT-8B) in Appendix B.
CV-9-2	Sandy Pseudosparite/Wackestone; sparsely fossiliferous with neomorphic spar destroying skeletal grains and micritic matrix. See duplicate slide (CV-9) in Appendix C.
CV-Abo-1 CV-Abo-2 CV-Abo-3	These slides were made from a cobble conglomerate found in the lower Abo Formation at site 5. Samples were collected when this conglomerate was considered part of the Bursum Formation. CV-Abo-1 is from a rounded, platy, metamorphic cobble. Identified as a phylite it has a silky sheen on exposed surfaces. In thin section oriented, elongate grains of quartz, feldspar, and mica have been identified. CV-Abo-2 is from a rounded, spherical cobble of granite gneiss. Coarse elongate crystals of oriented quartz, feldspar, and micas have been identified in thin section. CV-Abo-3 is a rounded spherical cobble of limestone. Fossil constituents of this limestone have been dissolved to form moldic porosity. Only pelmatozoans are identifiable from skeletal remains.
S-CU-X S-CU-Y S-CU-Z	Sample loction is SE 1/4, section 15, T. 2 S., R. 2 E., Socorro County, New Mexico. These slides were made from a lateral calcareous equivalent of unit 8 of site 2. S-CU-X was made from a thinly laminated carbonate. This slide shows alternating bands of very light to very dark gray carbonate. This unit has a fetid odor when broken and contains vertically oriented spar filled shrinkage cracks. The laminations here are attributed to algal growths. S-CU-Y was made from a sample similar to S-CU-X but contains disrupted laminae of mudcrack origin. S-CU-Z was

APPENDIX D (continued)

Sample Number	Description
	made from a mudcrack conglomerate that takes a red stain when Alizarin Red S is applied, but the intergranular matrix material does not take a stain which suggests dolomite.
S-CU-H1 S-CU-V1 S-CU-H2 S-CU-V2	Sample location in NE 1/4, section 9, T. 2 S., R. 2 S., Socorro County, New Mexico. These samples are from a zone laterally equivalent to unit 8 at site 2. These thin sections are horizontal and vertical cuts through an algal colony which is encrusting fossilized trees. This algal colony is of a lamellar form not further identified or described.
S-CU-M1 S-CU-M2 S-CU-M3 S-CU-M4 S-CU-M5	Sample location in SE 1/4, SE 1/4, section 9, T. 2 S., R. 2 E., Socorro County, New Mexico. These samples are from a zone laterally equivalent to unit 8 of site 2. All slides are vertical cuts through an algal encrusted fossil tree. S-CU-M1 and S-CU-M2 are from a zone where the algal encruster contacts the cellular woody area of the tree. S-CU-M3 and S-CU-M4 are from the center (pith) of the fossil tree. S-CU-M5 is from the algal encrustation zone.

APPENDIX E

RAW PALEOCURRENT DATA

APPENDIX E

LOCATION	UNIT	TYPE	TREND, PLUNGE	DIRECTION, DIP
SITE 1	CC-4	TROUGH	S62W, 22	N40W, 06
"	"	"	S65W, 22	" "
"	"	"	S45W, 14	" "
"	"	"	S04W, 24	N67W, 14
"	"	"	S60W, 19	" "
"	"	"	S85W, 16	" "
"	"	"	N60E, 10	S05E, 22
"	"	"	S00W, 27	S58W, 03
"	"	"	S20E, 06	" "
"	"	"	N55W, 11	" "
"	"	"	N55E, 11	" "
"	"	"	S54W, 19	" "
"	"	"	S40W, 21	" "
"	"	"	S28W, 18	" "
SITE 1	CC-18	O.RIPPLES	S25E, 13	S03E, 13
"	"	"	S27E, 13	" "
"	"	"	S26E, 13	" "
"	"	"	S19E, 14	" "
"	"	"	S23E, 14	" "
"	"	"	S22E, 14	" "
SITE 2	CU-27	TROUGH	N59E, 03	S87W, 14
"	"	"	N31E, 20	" "
"	"	"	S37W, 24	S17W, 10
"	"	"	S44W, 17	" "
"	"	"	S24E, 19	" "
"	"	"	S45E, 19	S13W, 03
"	"	"	S31E, 24	" "
"	"	"	S05E, 09	" "
"	"	"	S38W, 17	S17W, 07
"	"	"	N44W, 14	" "
"	"	"	N23W, 10	N70W, 27
"	"	"	N84E, 06	" "
"	"	"	N70E, 02	" "
"	"	"	N55W, 12	" "
"	"	"	N06W, 11	" "
"	"	"	S05E, 19	S30W, 12
SITE 2	CC-33	TROUGH	S09E, 42	S30W, 17
"	"	"	S45W, 37	" "
"	"	"	S10W, 26	" "
"	"	"	S26W, 36	" "
"	"	"	S10W, 39	" "
"	"	"	S33W, 21	N85W, 16
"	"	"	S09E, 19	S81W, 11
"	"	"	S07E, 27	S25W, 05
"	"	"	S33E, 18	S76W, 08
"	"	"	S33E, 12	S58W, 13
"	"	"	S90W, 30	S70W, 50

APPENDIX E (continued)

LOCATION	UNIT	TYPE	TREND, PLUNGE	DIRECTION, DIP
SITE 2	CC-33	LOG AXES	N53W, 09	S55W, 09
"	"	"	N82W, 09	" "
"	"	"	N83W, 09	" "
"	"	"	N82W, 09	" "
"	"	"	N70W, 09	" "
"	"	"	N54W, 09	" "
"	"	"	N68W, 09	" "
"	"	"	N66W, 09	" "
"	"	"	N77E, 09	" "
"	"	"	N60E, 09	" "
"	"	"	N68E, 09	" "
"	"	"	N56W, 09	" "
"	"	"	N67E, 09	" "
"	"	"	N81E, 09	" "
"	"	"	N63E, 09	" "
"	"	"	N74E, 09	" "
"	"	"	N86E, 09	" "
"	"	"	N57W, 09	" "
"	"	"	N90W, 09	" "
"	"	"	N37E, 09	" "
"	"	"	N85E, 09	" "
"	"	"	N79E, 09	" "
"	"	"	N69E, 09	" "
"	"	"	N27W, 09	" "
"	"	"	N75W, 09	" "
SITE 3	DC-8	TABULAR	N83W, 09	N29E, 03
"	"	"	N71W, 14	" "
"	"	"	S55W, 12	" "
"	"	"	S56W, 12	" "
"	"	"	S68W, 04	" "
"	"	"	S46W, 26	" "
"	"	"	N84W, 12	" "
"	"	"	S61W, 11	S44E, 06
"	"	"	S57W, 12	S66E, 27
SITE 4	AT-2	TROUGH	S48E, 12	S40E, 04
"	"	"	S19E, 11	" "
"	"	"	S10W, 26	" "
"	"	"	S10E, 09	" "
"	"	"	S03W, 18	" "
"	"	"	S06E, 26	" "
"	"	"	S13E, 14	" "
"	"	"	S44E, 18	" "
"	"	"	S57E, 18	S27E, 05
"	"	"	S51E, 16	" "
"	"	"	S33E, 12	" "
"	"	"	S63E, 19	" "
"	"	"	S41E, 21	" "
"	"	"	S63E, 18	" "

APPENDIX E (continued)

LOCATION	UNIT	TYPE	TREND, PLUNGE	DIRECTION, DIP
SITE 4	AT-21	TABULAR	N30W, 33	S69E, 05
"	"	"	N35W, 25	" "
"	"	"	N55W, 38	" "
"	"	"	N14W, 18	S66E, 05
"	"	"	N90W, 21	" "
"	"	"	N12W, 17	" "
"	"	"	N11W, 25	" "
"	"	"	N49W, 42	N85E, 07
SITE 5	CV-7	TROUGH	S56E, 25	S85E, 19
"	"	"	S60W, 22	" "
"	"	"	S90W, 07	" "
"	"	"	S62W, 05	" "
"	"	"	S53W, 25	" "
"	"	"	S47W, 18	" "
"	"	"	S65W, 20	" "
"	"	"	S70W, 17	" "
"	"	"	N62W, 12	" "
"	"	"	S28W, 17	" "
"	"	"	S68E, 02	" "
"	"	"	S71E, 27	" "

APPENDIX F

ROSE DIAGRAMS OF TABULATED PALEOCURRENT DATA

APPENDIX F

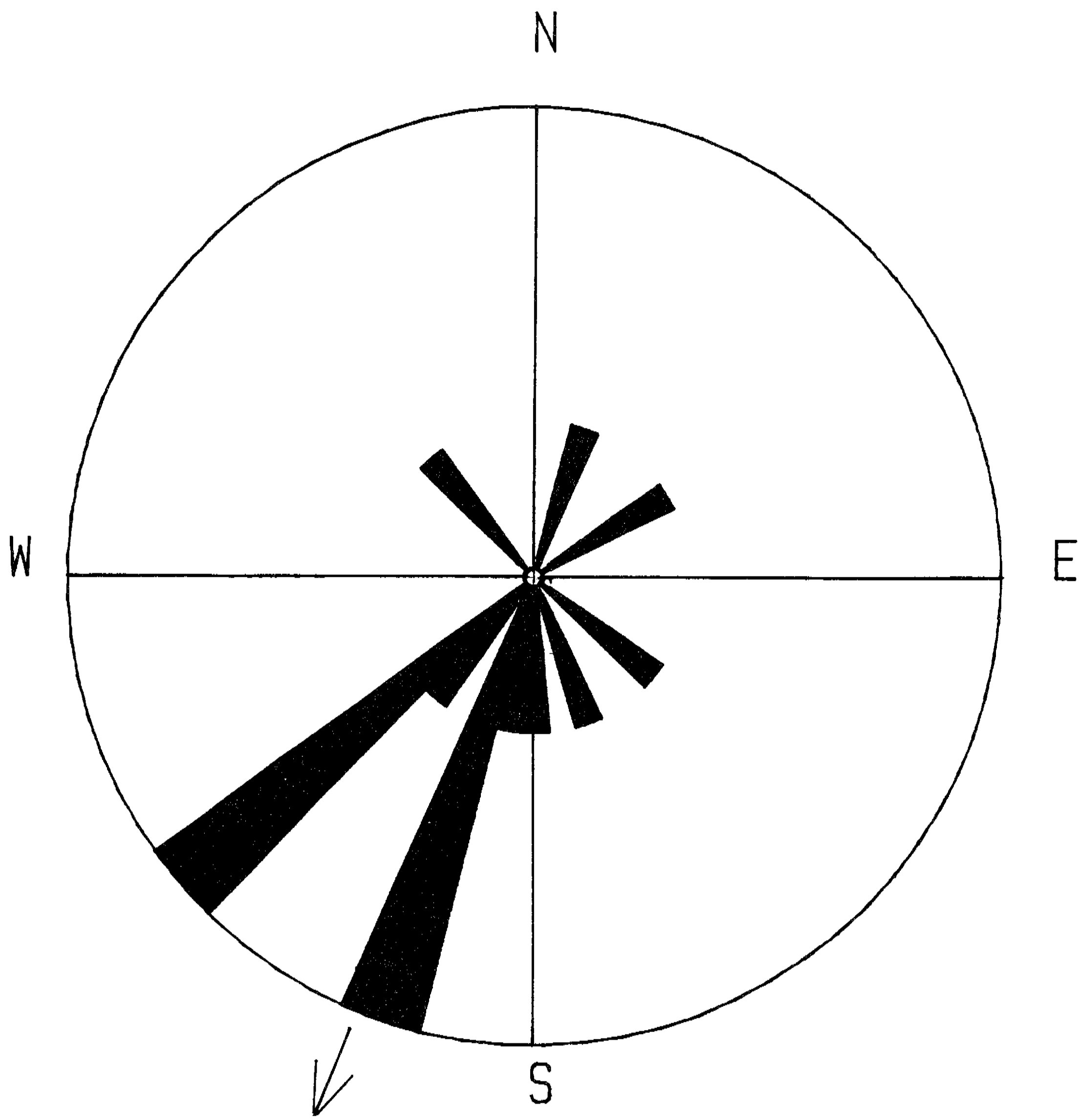


Figure 33: Rose diagram of medium-scale trough-shaped crossbeds from unit 4 at site 1. N=14, Radius=3, vector mean=202.0 (indicated by arrow), vector strength=0.52.

APPENDIX F (continued)

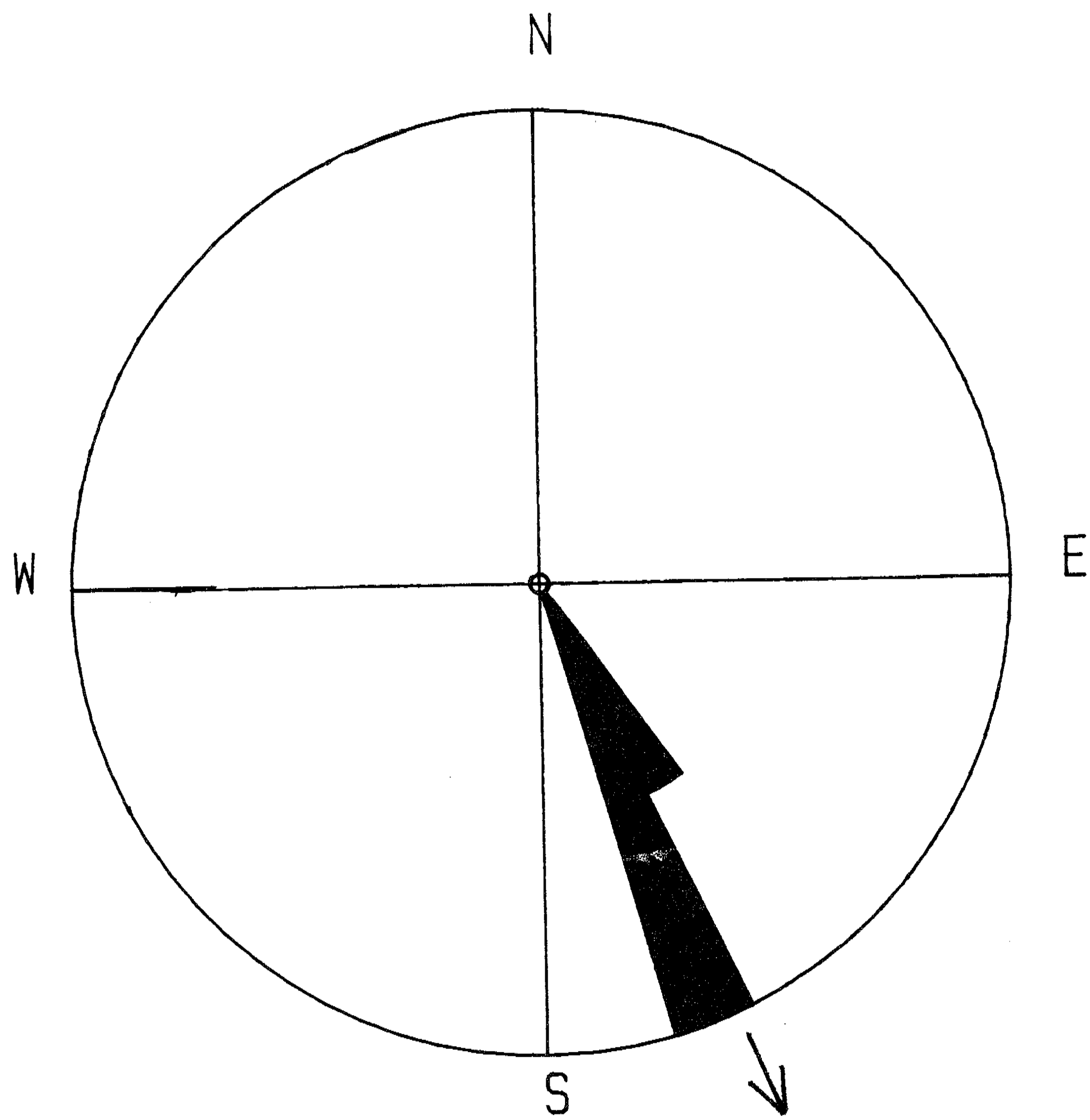


Figure 34: Rose diagram (eastern hemisphere only) of oscillation ripple crest orientations from unit 18 at site 1. N=6, radius=4, vector mean=156.3 (indicated by arrow), vector strength =0.99.

APPENDIX F (continued)

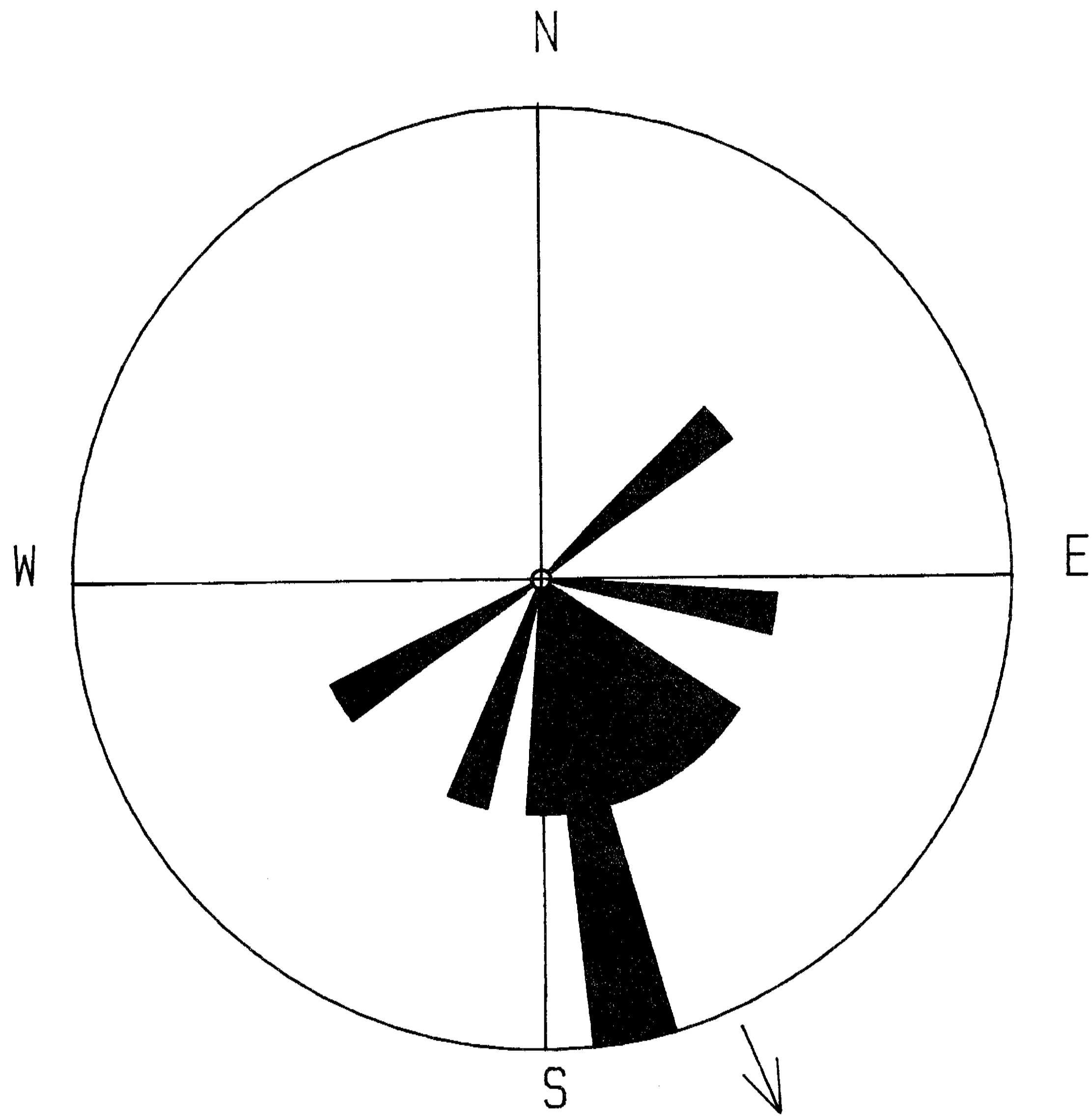


Figure 35: Rose diagram of medium-scale trough-shaped crossbeds from unit 27 at site 2. N=11, radius=2, vector mean=156.4 (indicated by arrow), vector strength=0.71.

APPENDIX F (continued)

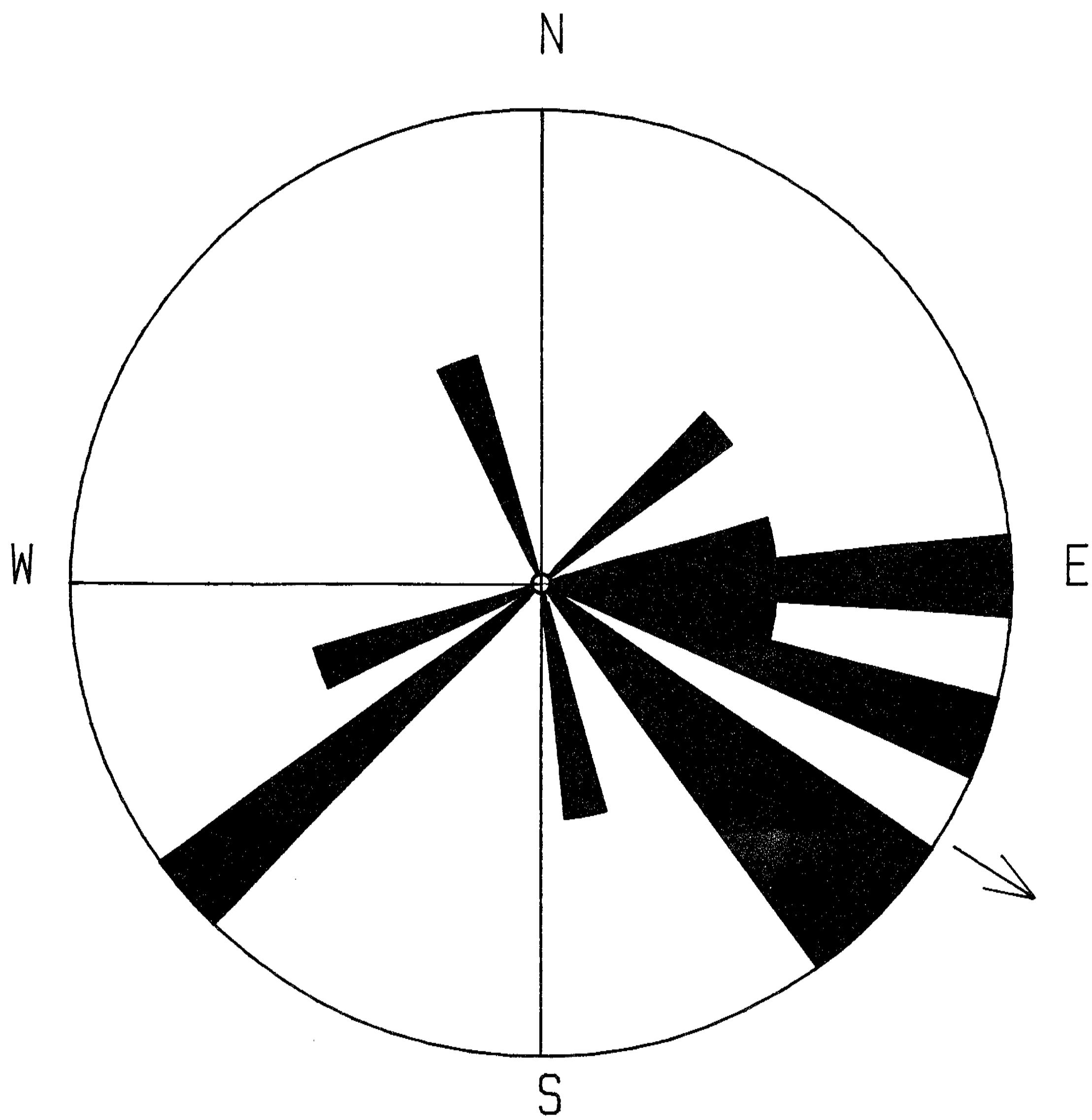


Figure 36: Rose diagram of medium-scale trough-shaped crossbeds from unit 33 at site 2. N=16, radius=2, vector mean=122.3 (indicated by arrow), vector strength=0.51.

APPENDIX F (continued)

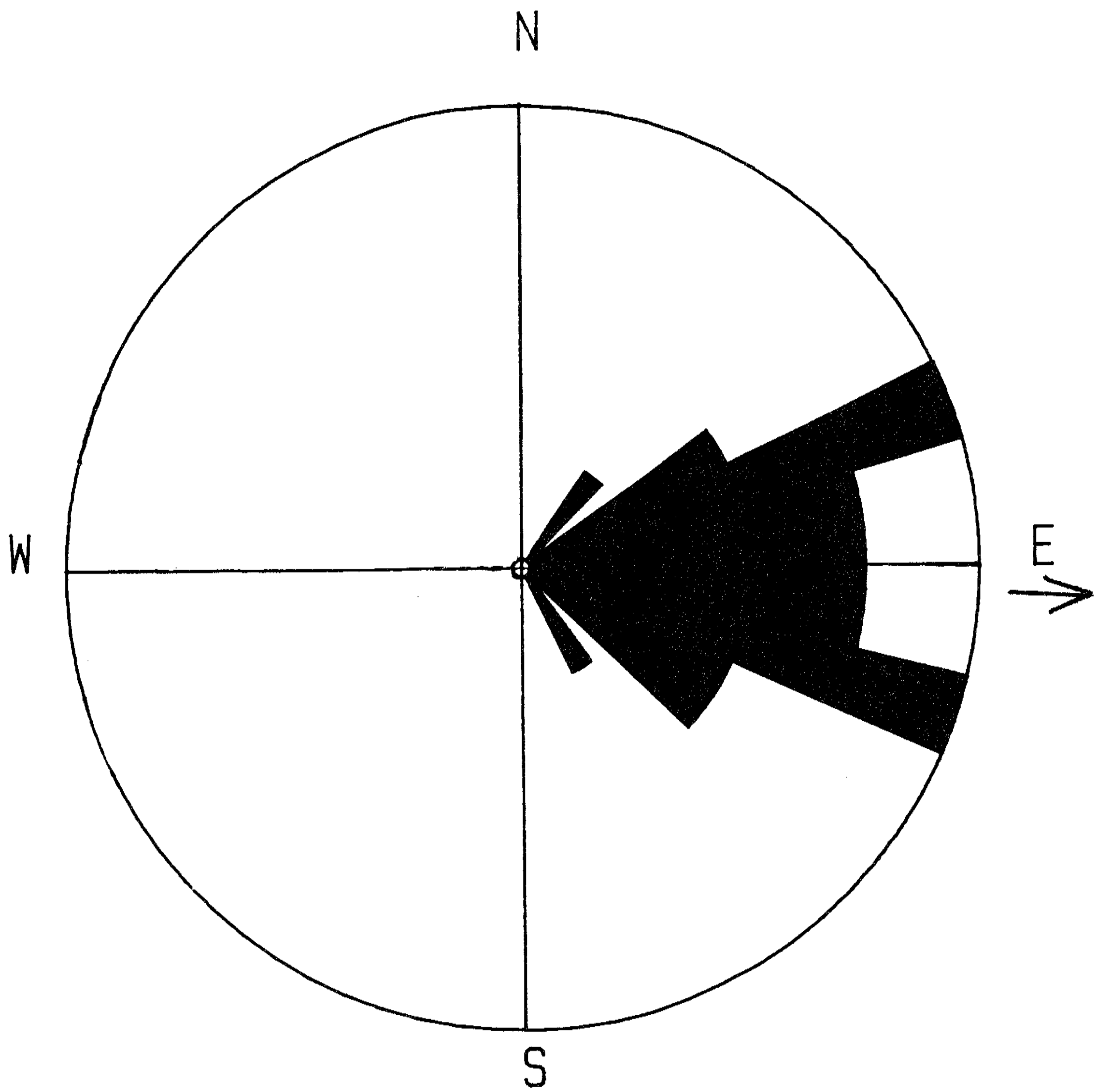


Figure 37: Rose diagram of long axes of log orientations (eastern hemisphere only) from unit 33 at site 2. N=25, radius=4, vector mean=92.8 (indicated by arrow), vector strength=0.90.

APPENDIX F (continued)

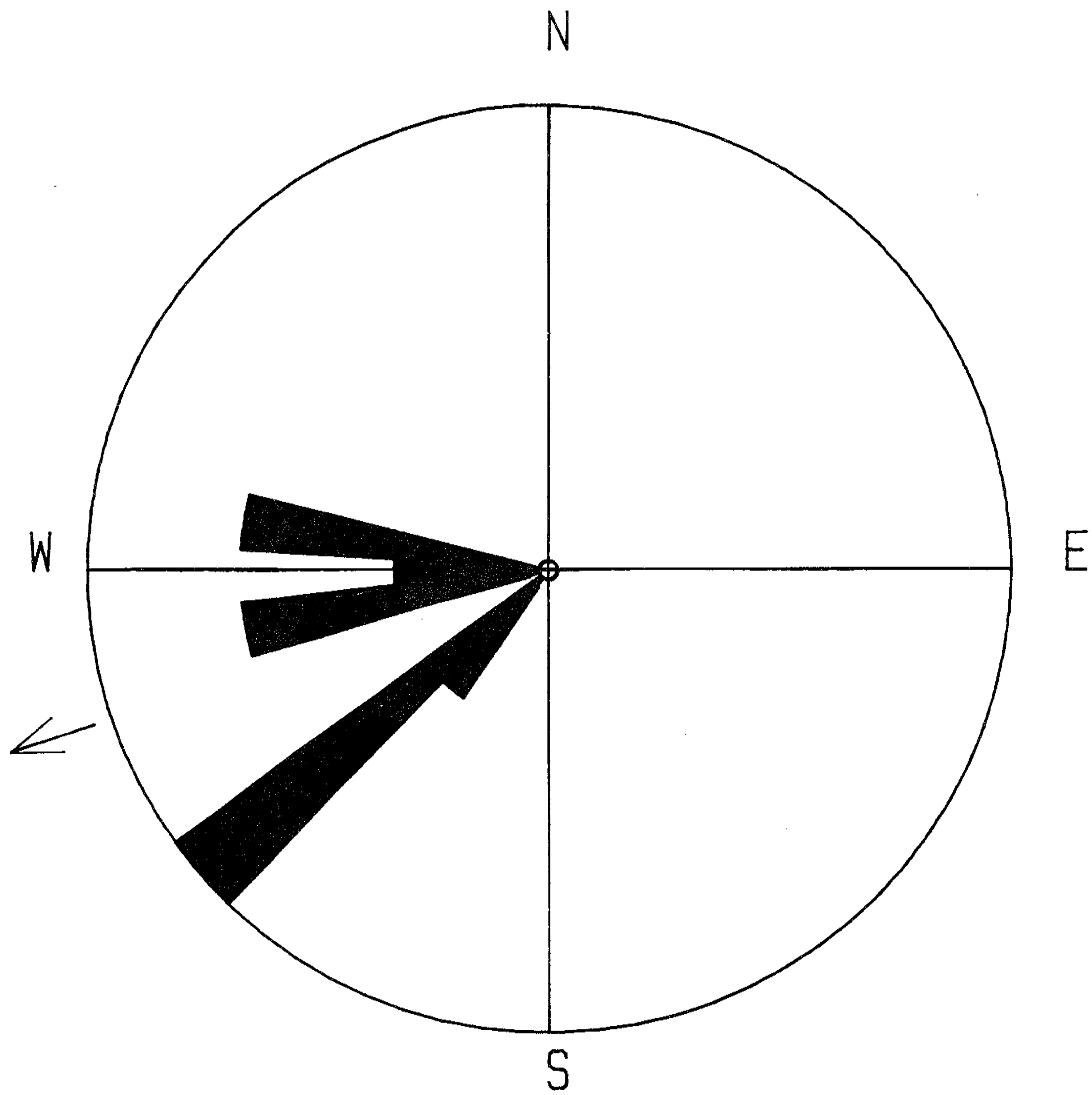


Figure 38: Rose diagram of medium-scale tabular-shaped crossbeds from unit 8 at site 3. N=9, radius=3, vector mean=251.4 (indicated by arrow), vector strength=0.94.

APPENDIX F (continued)

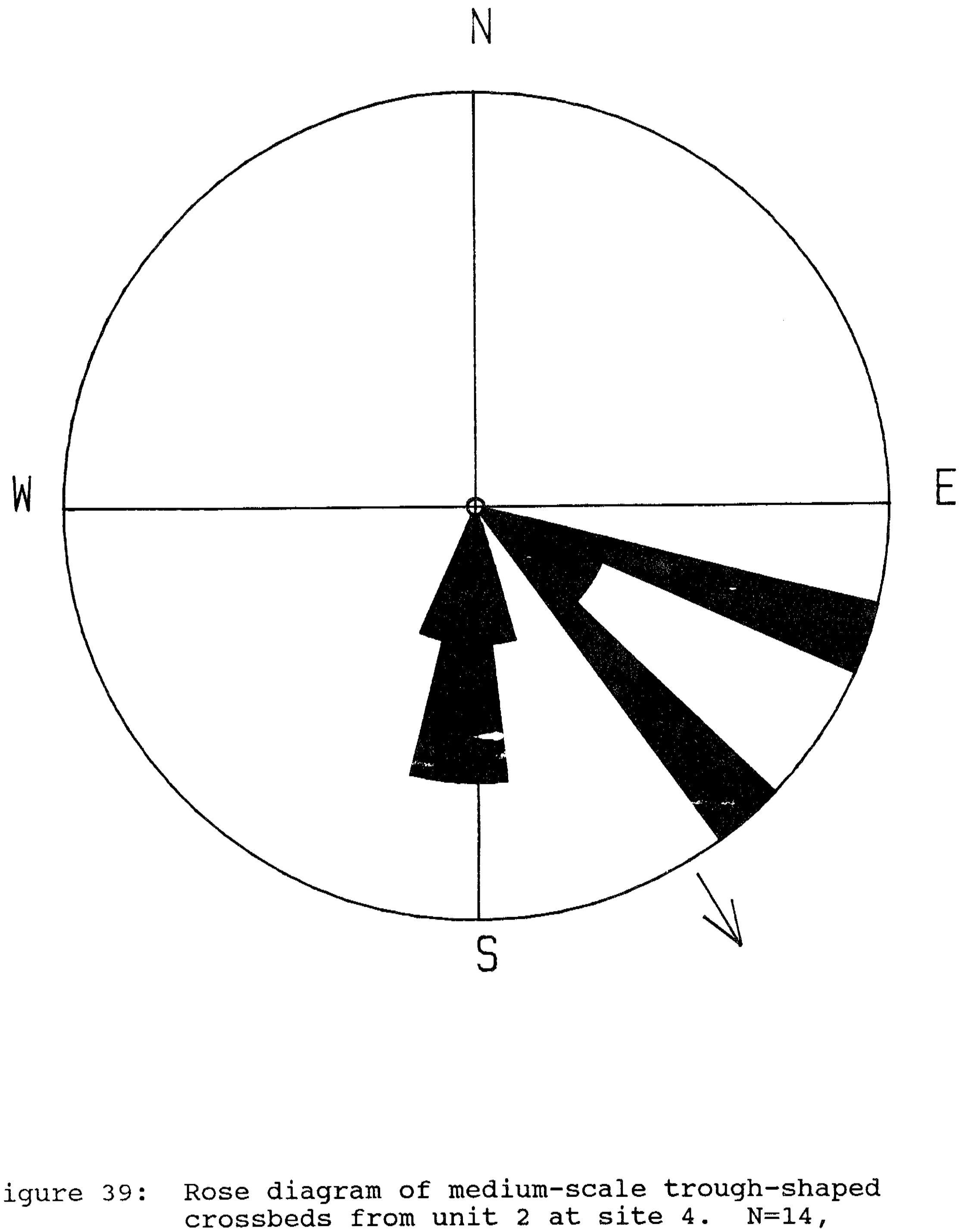


Figure 39: Rose diagram of medium-scale trough-shaped crossbeds from unit 2 at site 4. N=14, radius=3, vector mean=149.2 (indicated by arrow), vector strength=0.84.

APPENDIX F (continued)

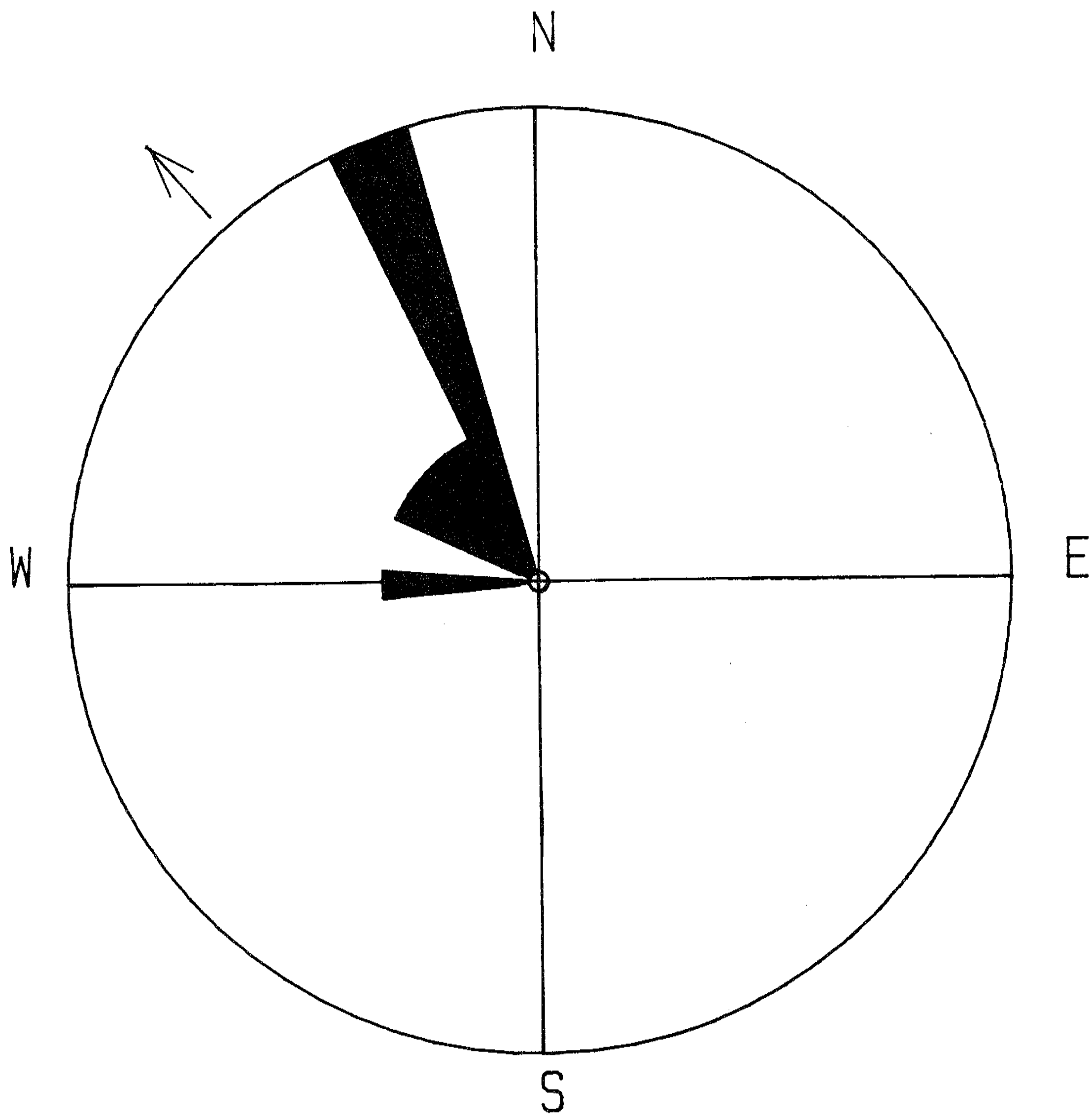


Figure 40: Rose diagram of medium-scale tabular-shaped crossbeds from unit 23 at site 4. N=8, radius=3, vector mean=318.3 (indicated by arrow), vector strength=0.93.

APPENDIX F (continued)

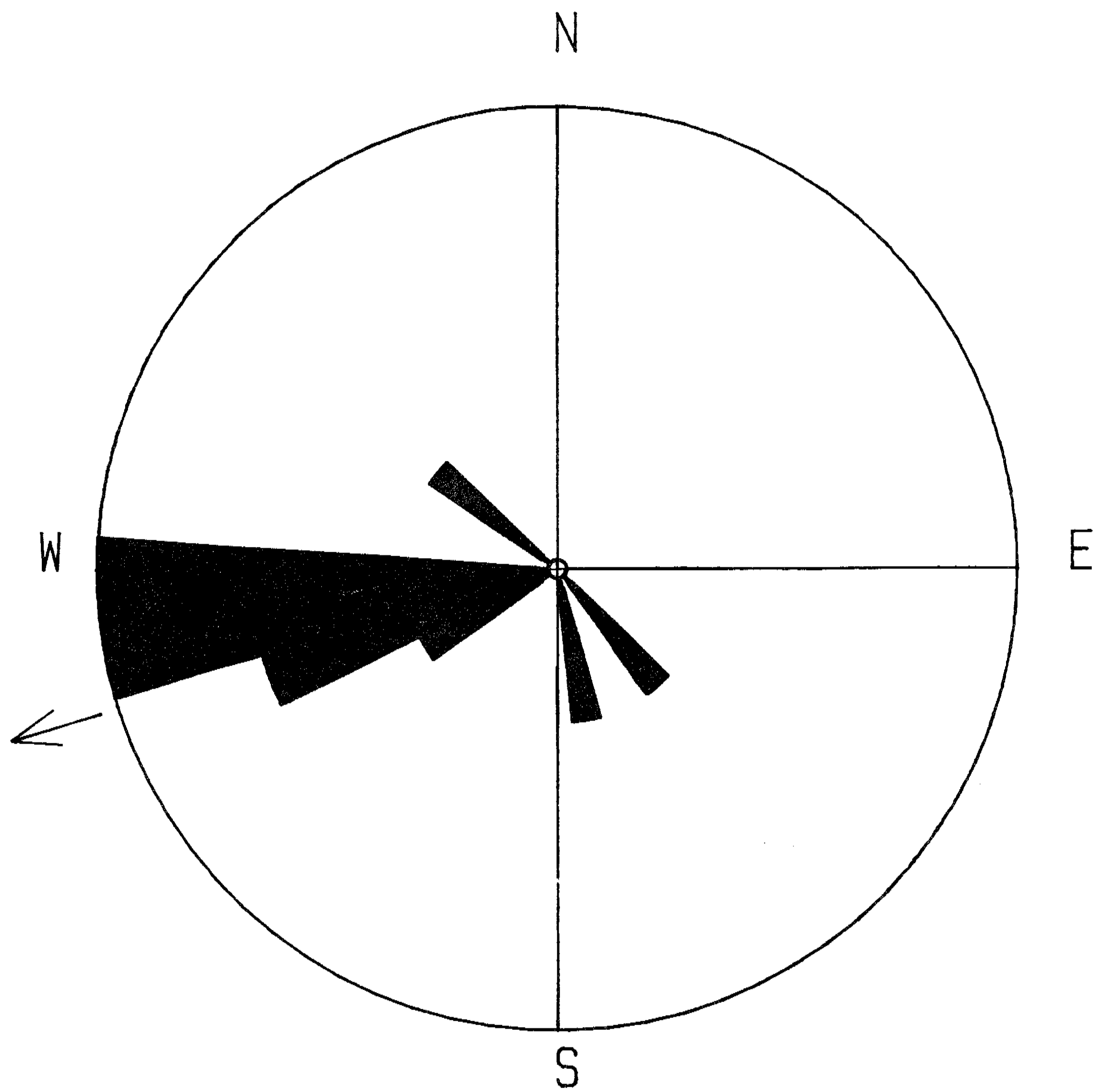


Figure 41: Rose diagram of medium-scale trough-shaped crossbeds from unit 7 at site 5. N=12, radius=3, vector mean=252.6 (indicated by arrow), vector strength=0.75.

APPENDIX G

THIN SECTION SAMPLE AND STRATIGRAPHIC SECTION LOCATOR MAPS

APPENDIX G

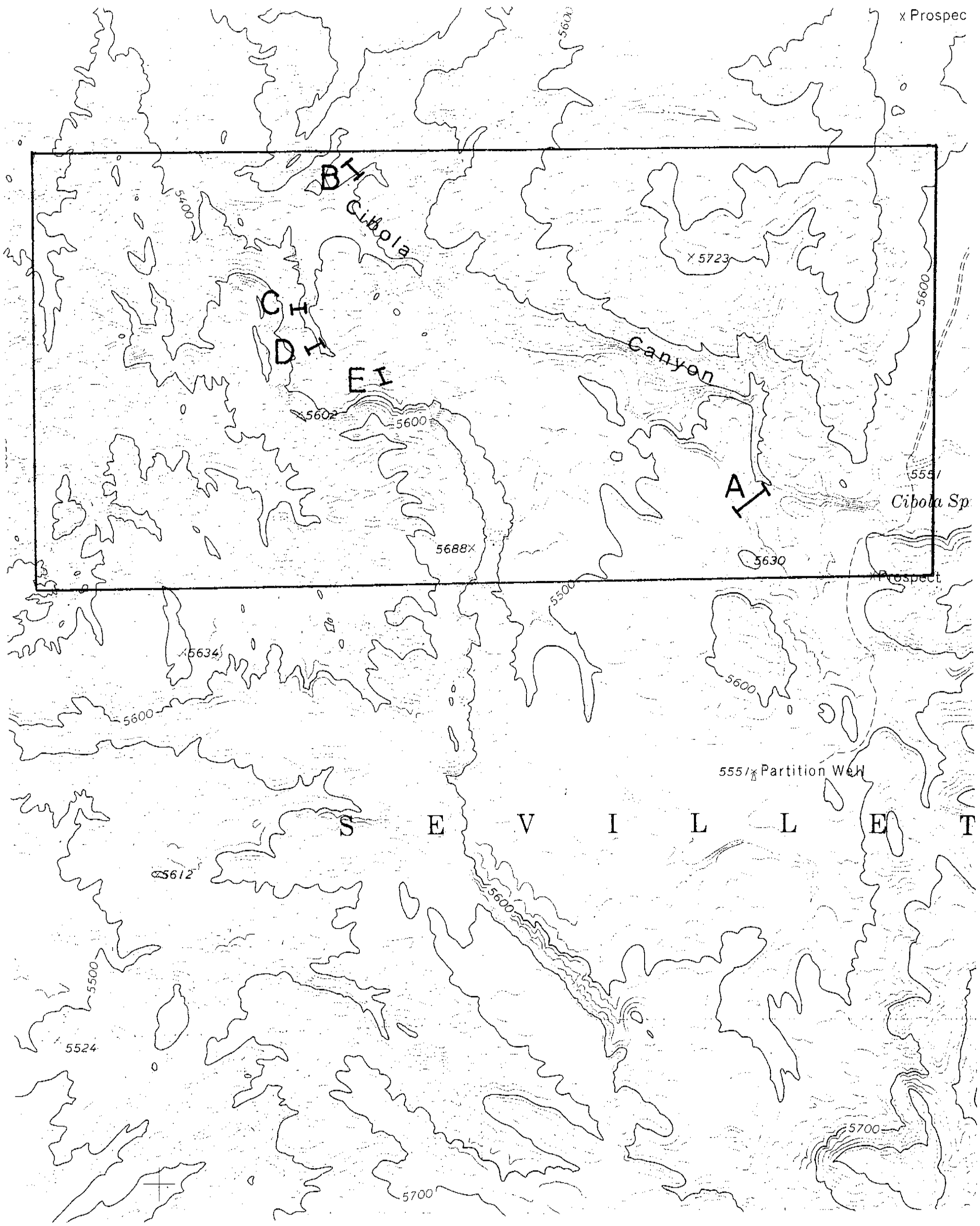


Figure 42: Location of measured strata at site 1. Measured section letters (A-E) correspond to measured section column on Figure 43 (Field location E 1/2 Section 11 and W 1/2 Section 12, projected, T. 1 S., R. 2 E., Socorro County, New Mexico).

APPENDIX G (continued)

Site I— Cibola Canyon (CC)

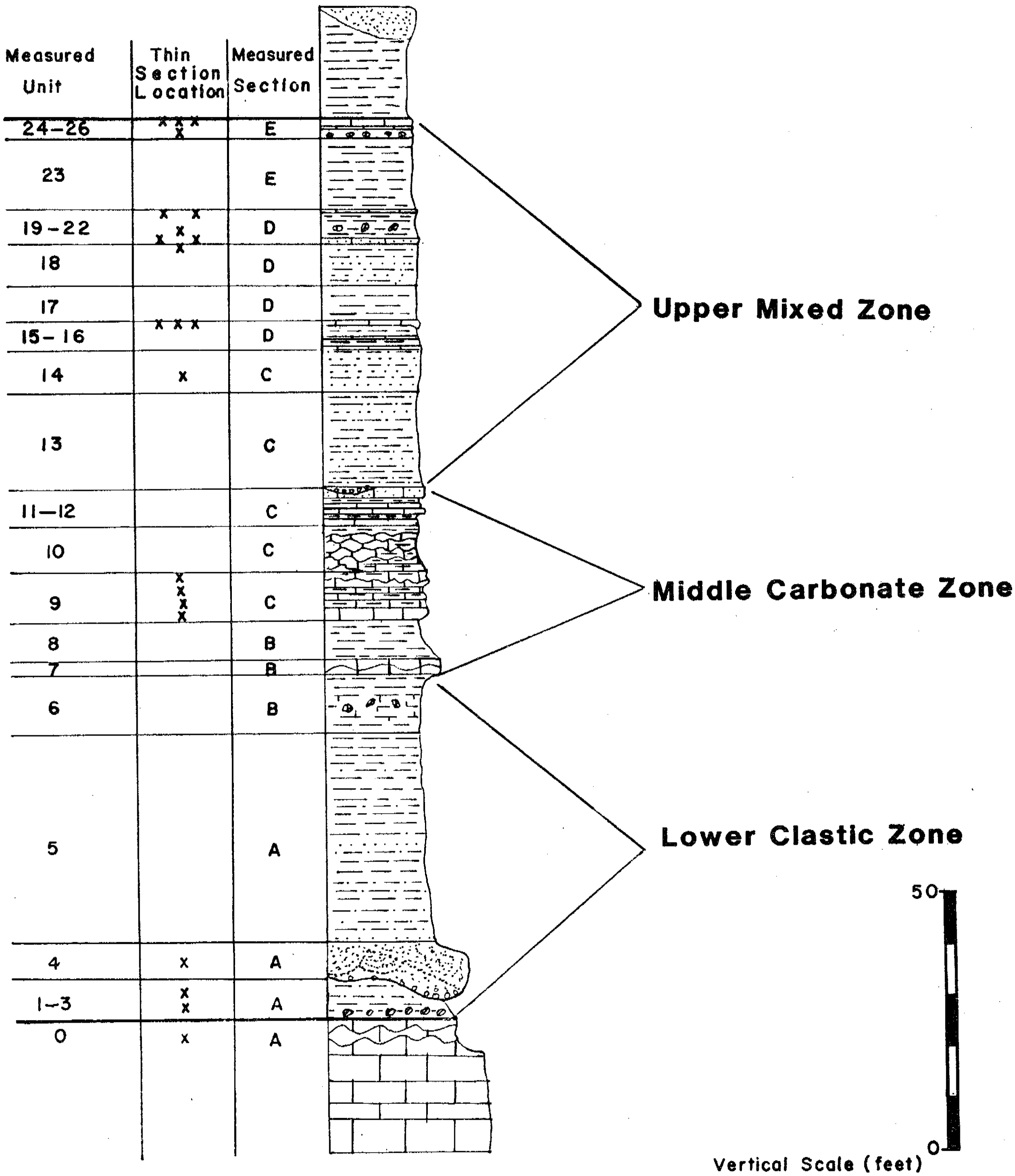


Figure 43: Stratigraphic column of site 1 showing thin section sample locations and measured sections.

APPENDIX G (continued)

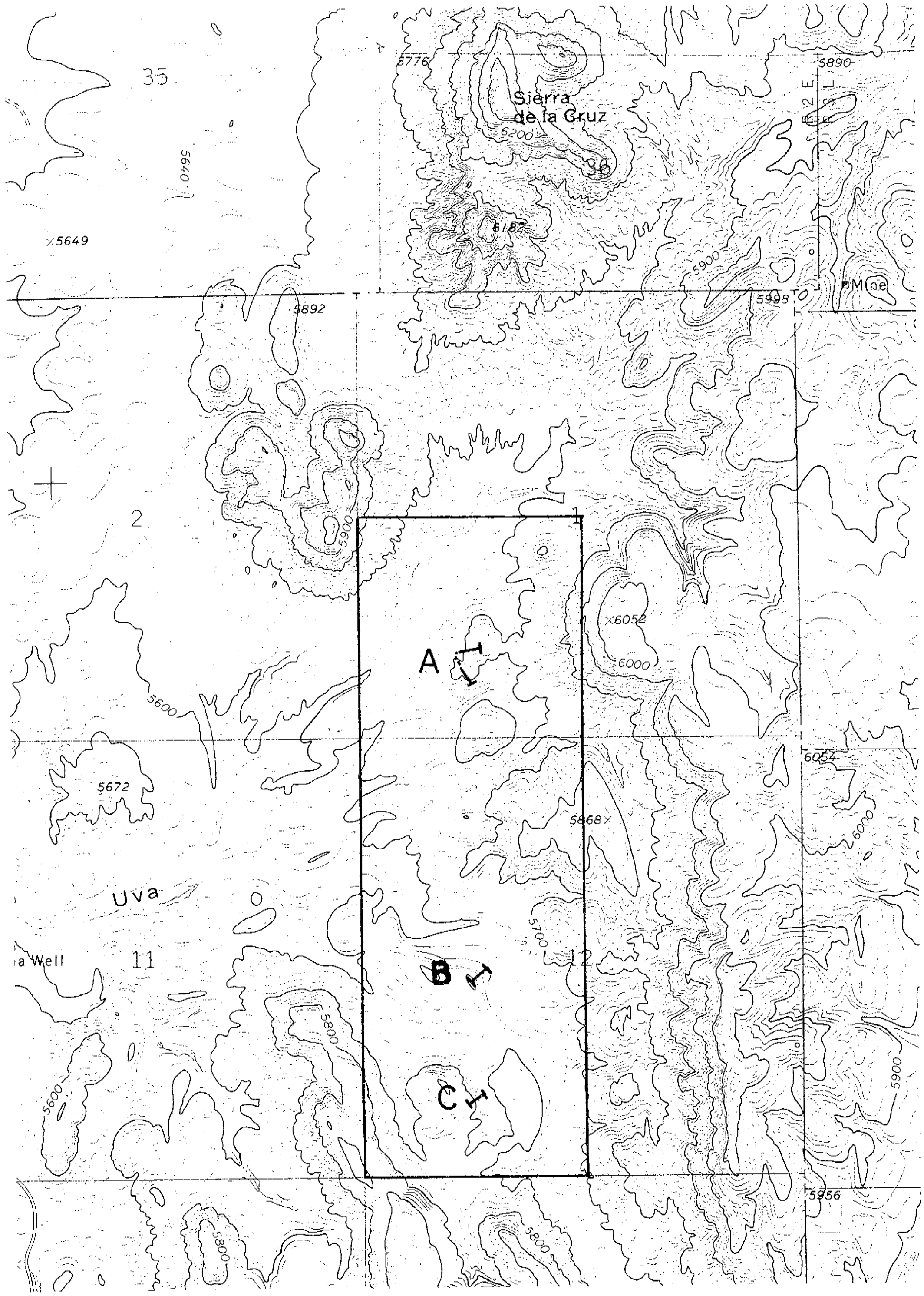


Figure 44: Location of measured strata at site 2. Measured section letters (A-C) correspond to the measured section column on Figure 45 (Field location SW 1/4 Section 1 and W 1/2 Section 12, T. 2 S., R. 2 E., Socorro County, New Mexico).

APPENDIX G (continued)

Site 2– Canoncito de la Uva (CU)

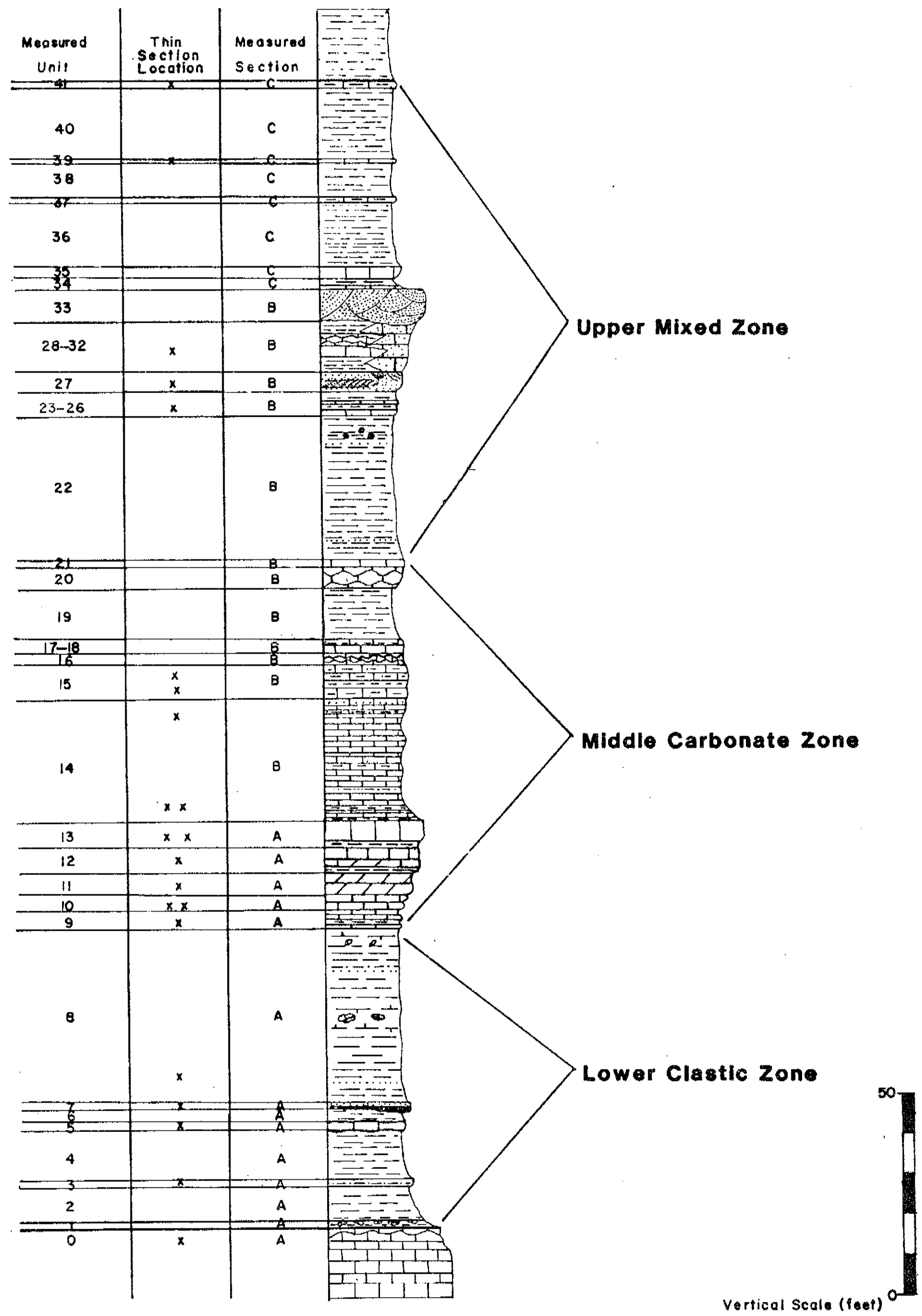


Figure 45: Stratigraphic column of site 2 showing thin section sample locations and measured sections.

APPENDIX G (continued)

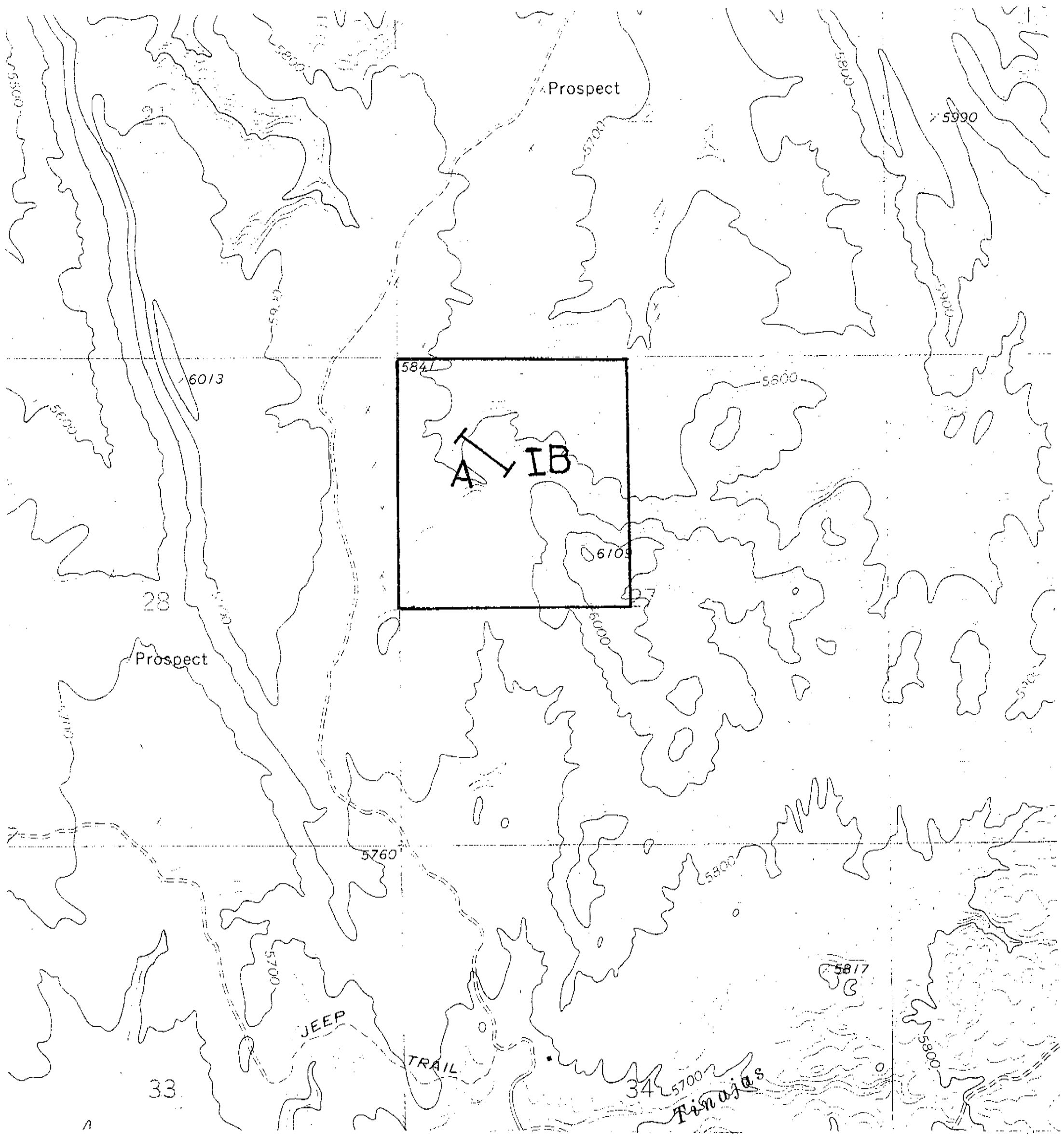


Figure 46: Location of measured strata at site 3. Measured section letters (A and B) correspond to the measured section column on Figure 47 (Field location NW 1/4 Section 27, T. 2 S., R. 2 E., Socorro County, New Mexico).

APPENDIX G (continued)

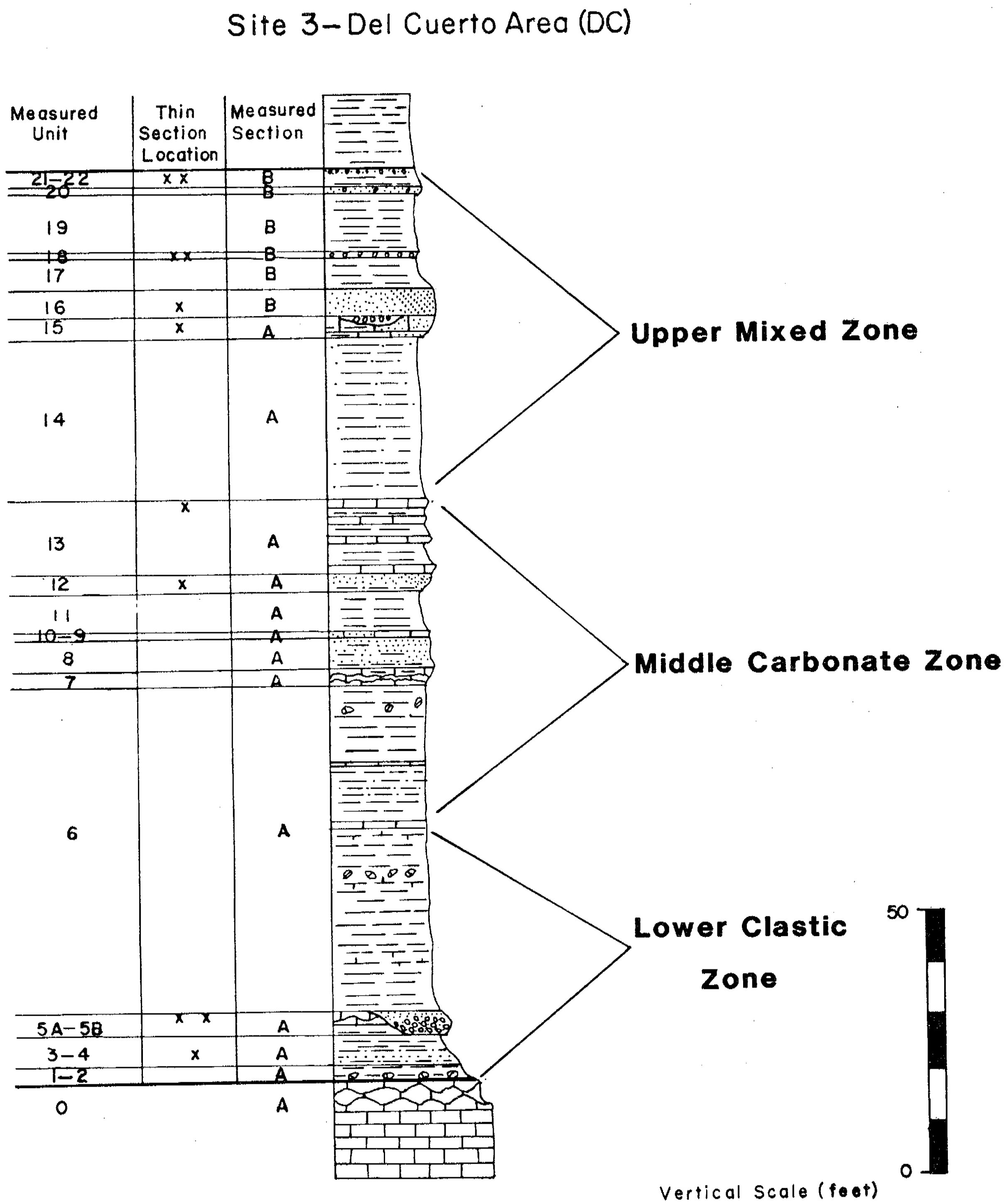


Figure 47: Stratigraphic column of site 3 showing thin section sample locations and measured sections.

APPENDIX G (continued)

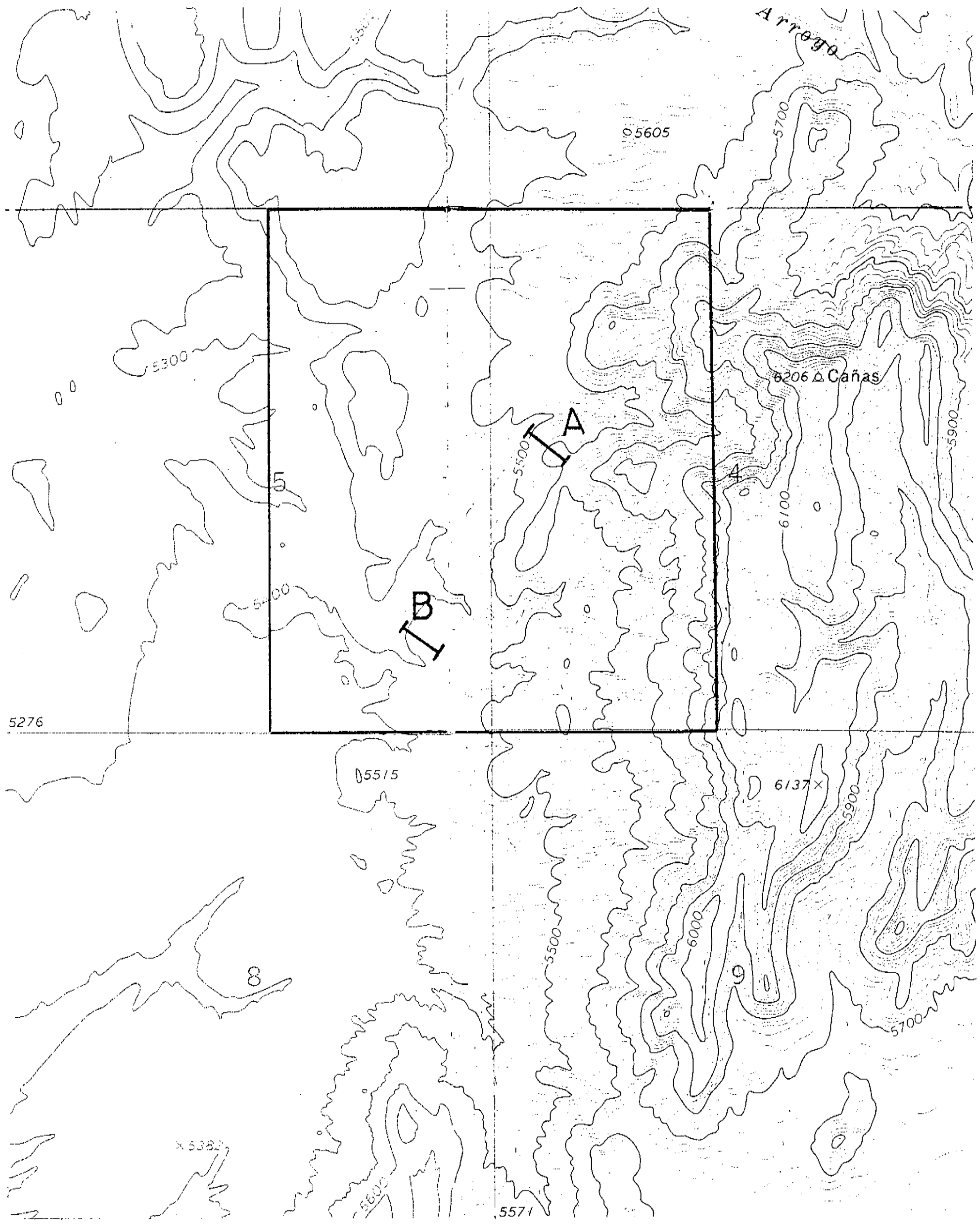


Figure 48: Location of measured strata at site 4. Measured section letters (A and B) correspond to the measured section column on Figure 49 (Field location E 1/2 Section 5 and W 1/2 Section 4, T. 3 S., R. 2 E., Socorro County, New Mexico).

APPENDIX G (continued)

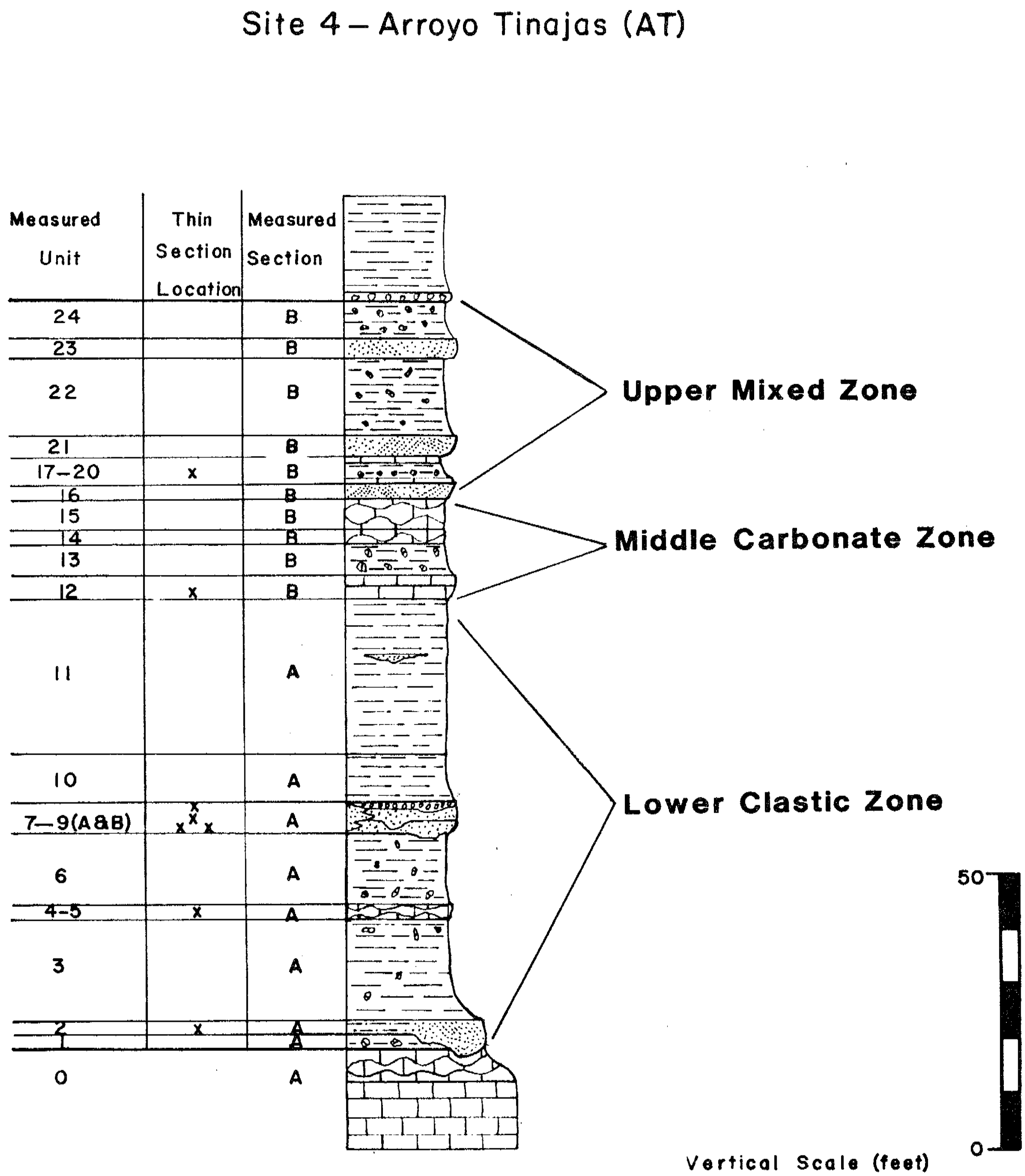


Figure 49: Stratigraphic column of site 4 showing thin section sample locations and measured sections.

APPENDIX G (continued)

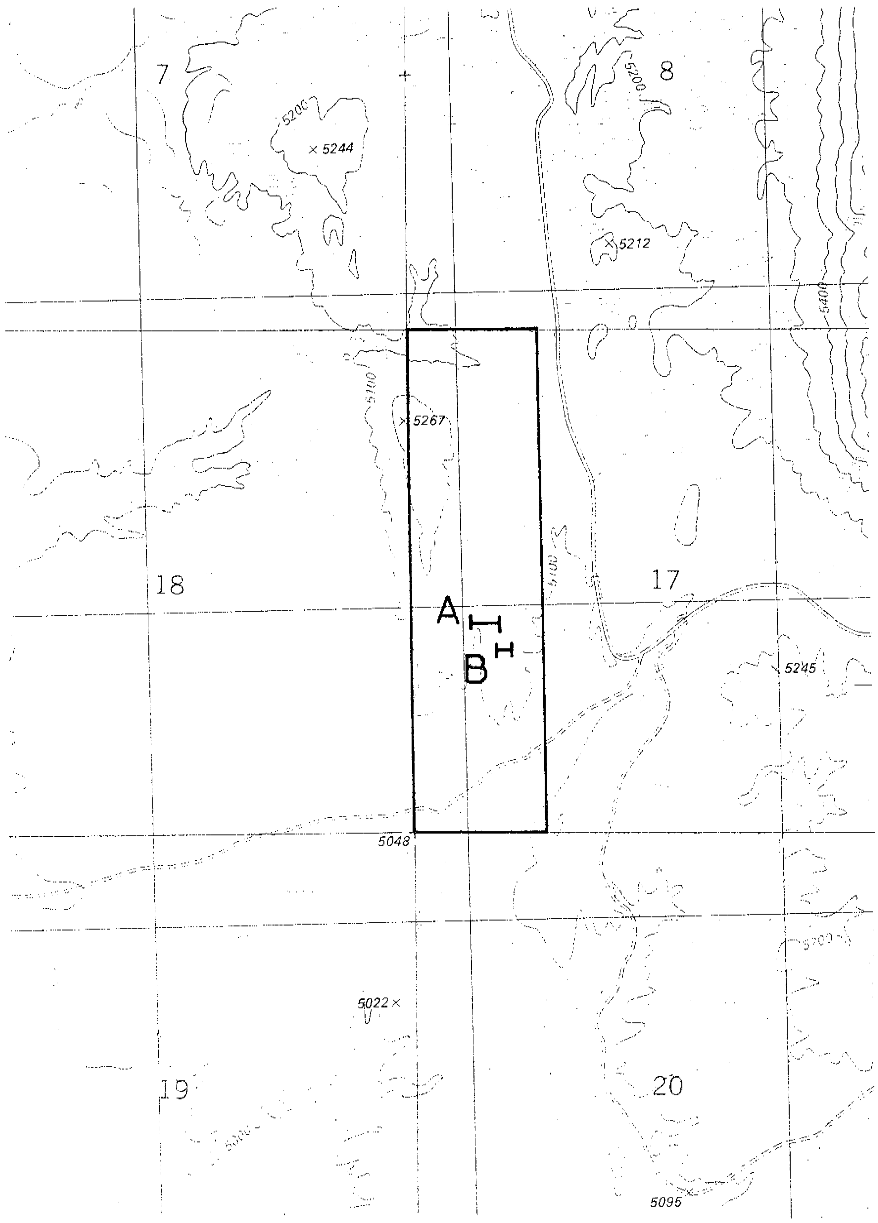


Figure 50: Location of measured strata at site 5. Measured section letters (A and B) correspond to the measured section column on Figure 51 (Field location W 1/4 Section 17, T. 4 S., R. 2 E, Socorro County, New Mexico).

APPENDIX G (continued)

Site 5– Cerro del Viboro Area (CV)

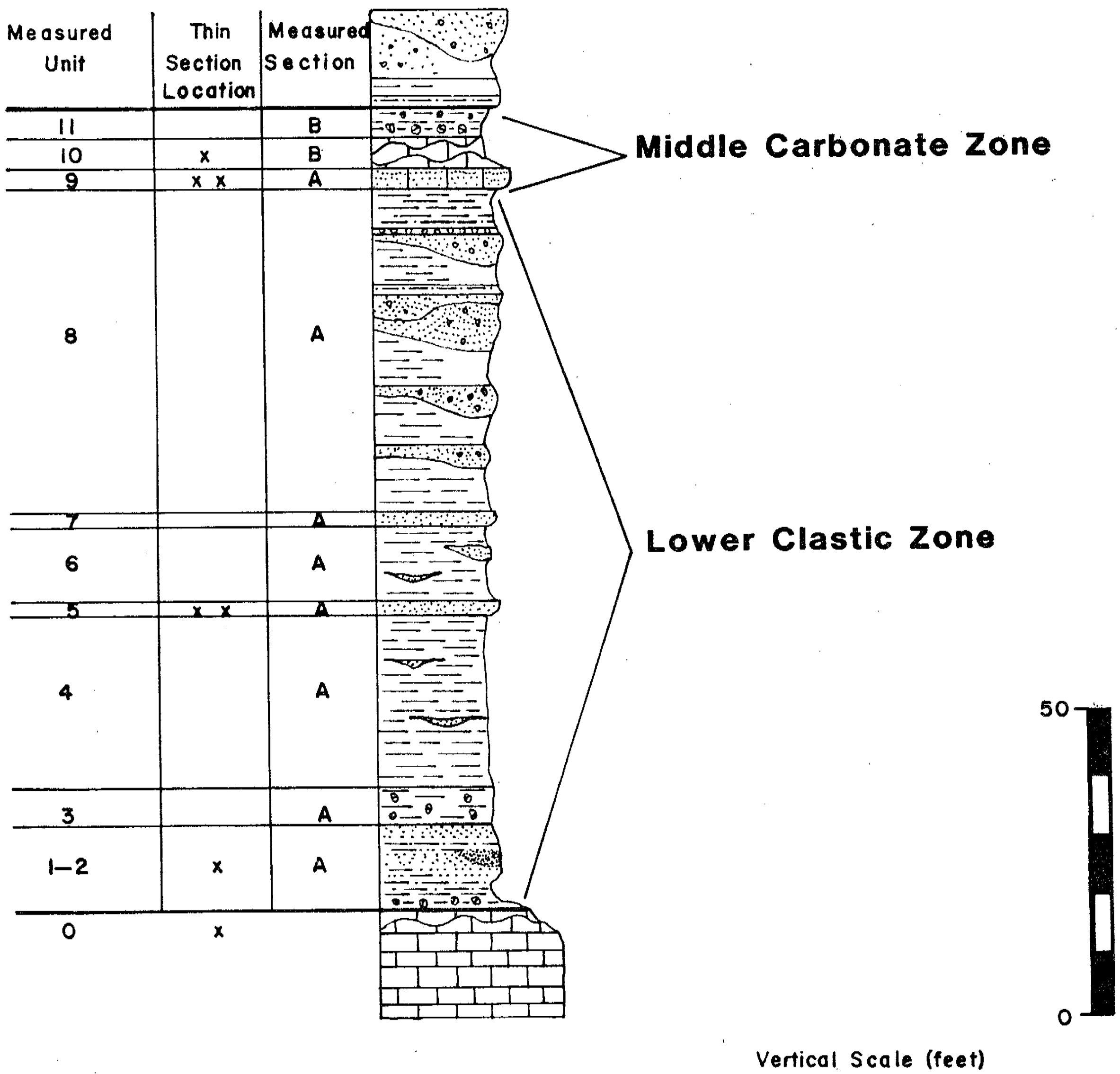


Figure 51: Stratigraphic column at site 5 showing thin section sample locations and measured sections.

APPENDIX H

BIOTIC DIVERSITY CHARTS

APPENDIX H

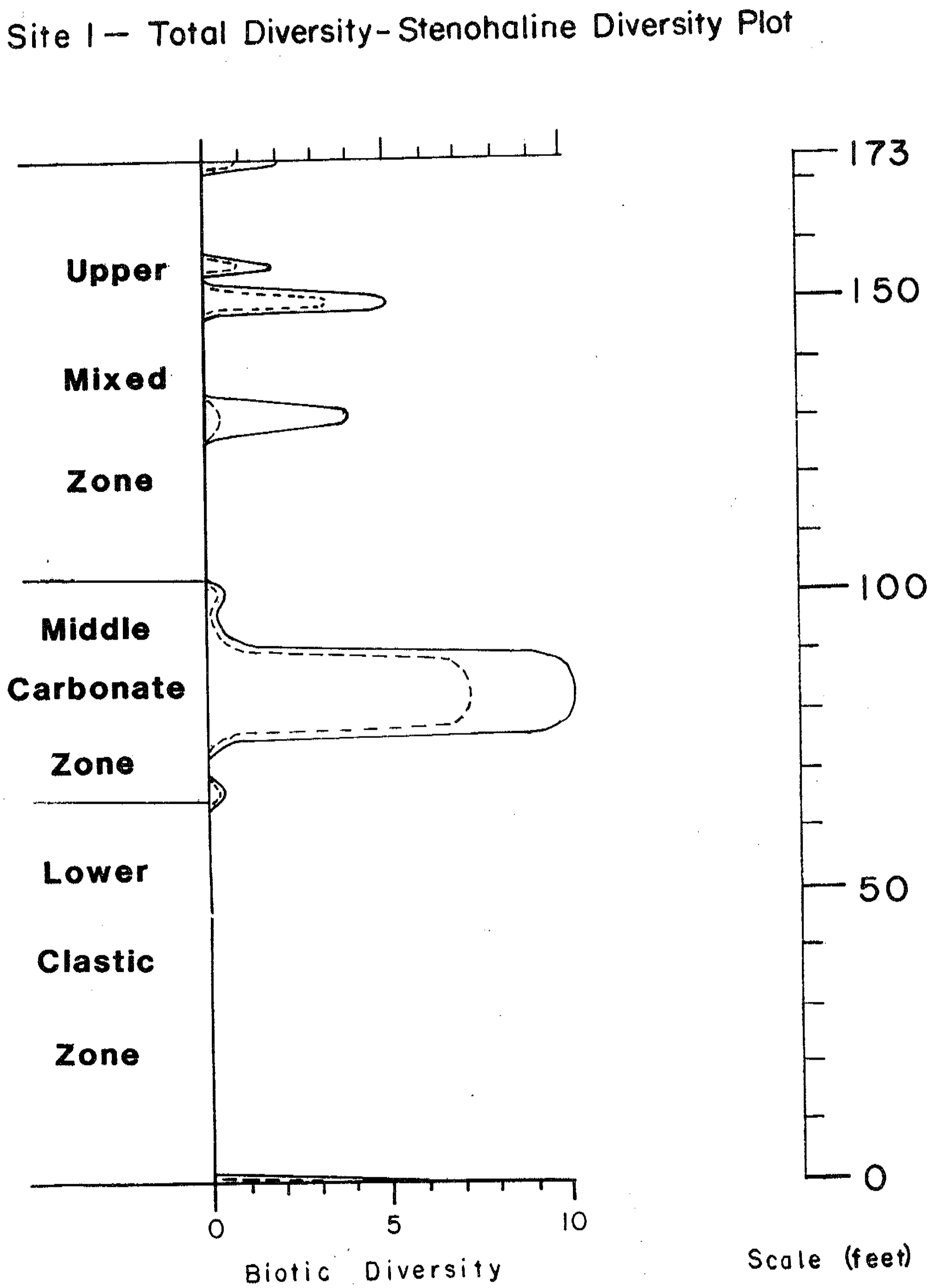


Figure 52: Biotic diversity plot for site 1. Solid line represents total diversity and dashed line represents stenohaline diversity. Moving averages are used to smooth peaks.

APPENDIX H (continued)

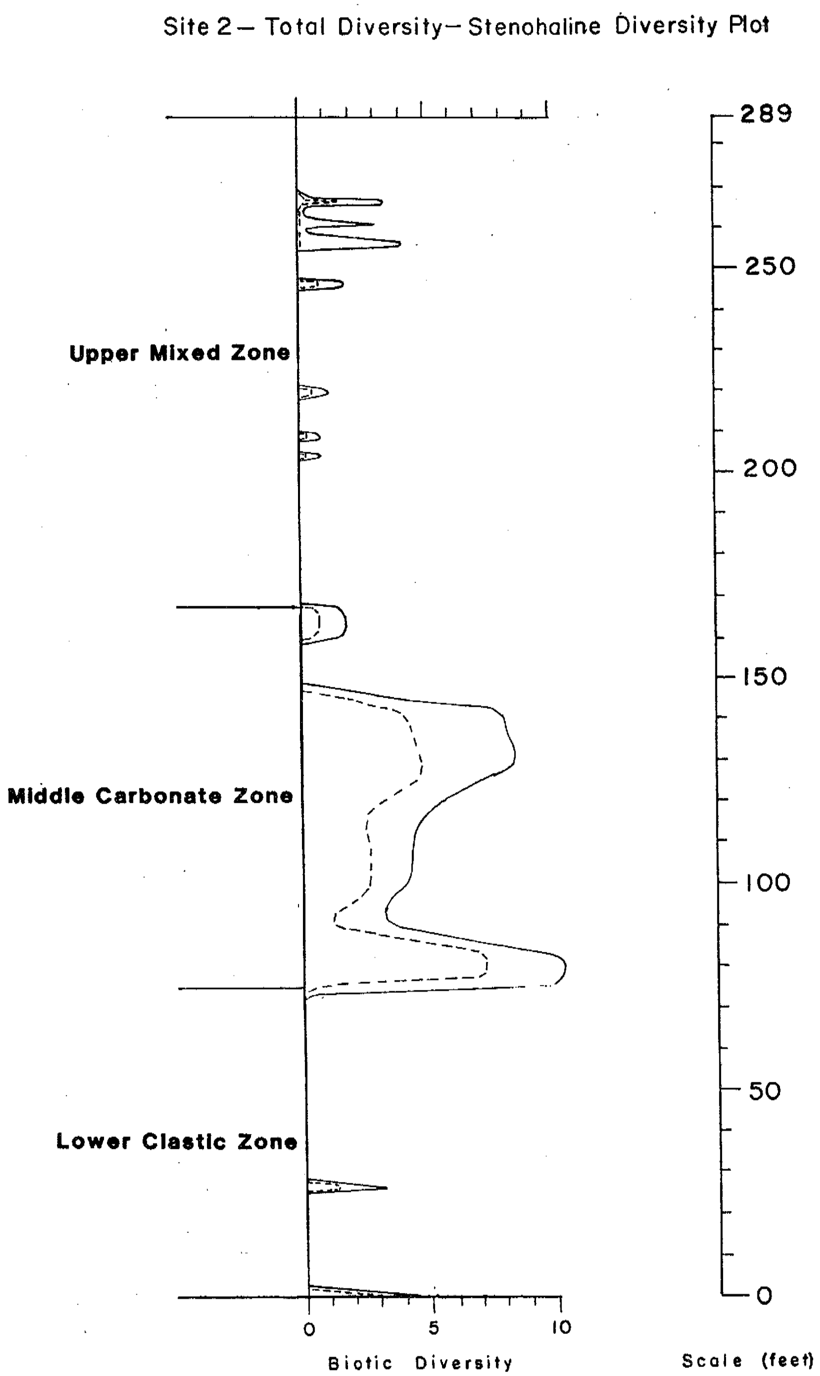


Figure 53: Biotic diversity plot for site 2. Solid line represents total diversity and dashed line represents stenohaline diversity. Moving averages are used to smooth peaks.

APPENDIX H (continued)

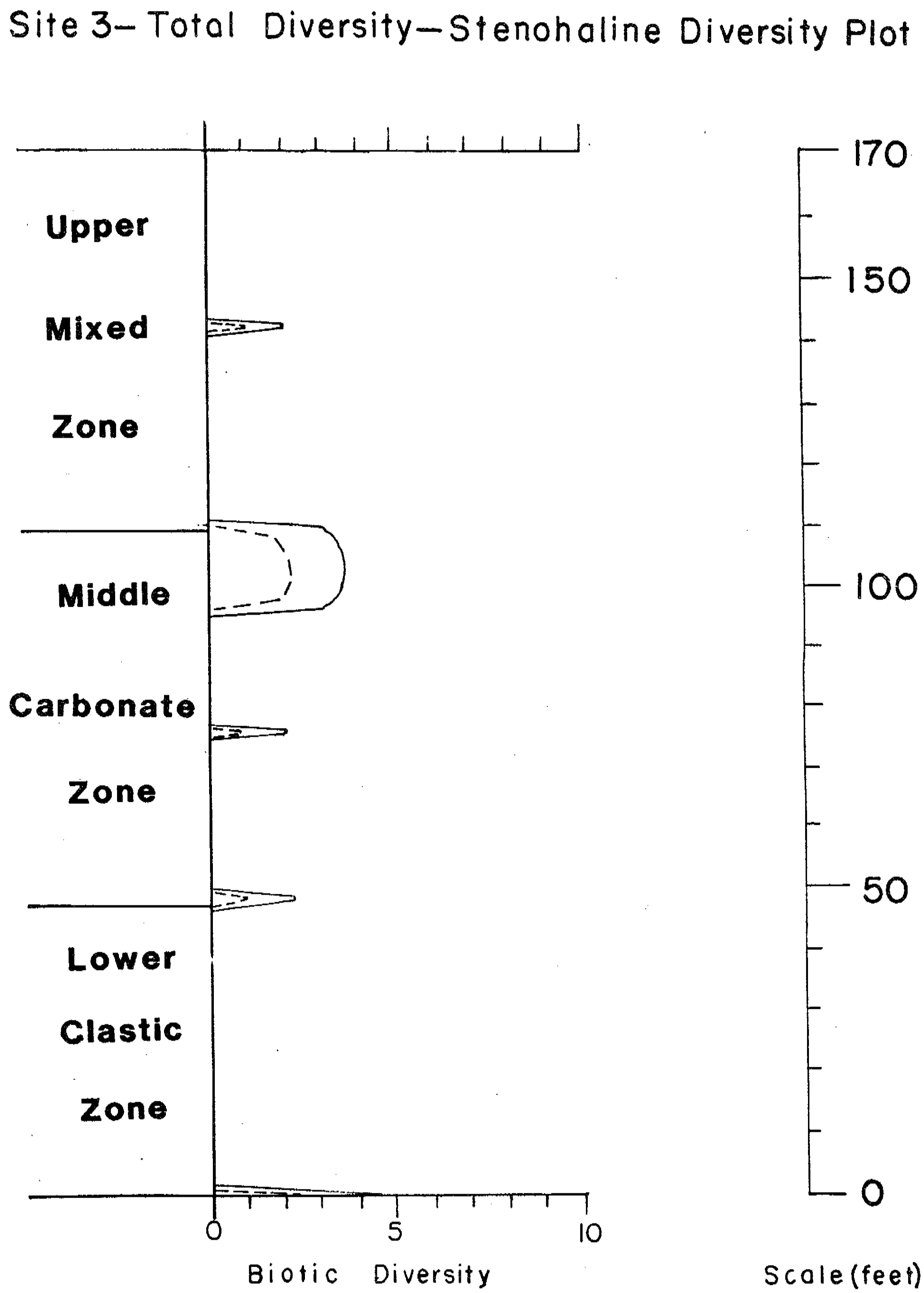


Figure 54: Biotic diversity plot for site 3. Solid line represents total diversity and dashed line represents stenohaline diversity. Moving averages are used to smooth peaks.

APPENDIX H (continued)

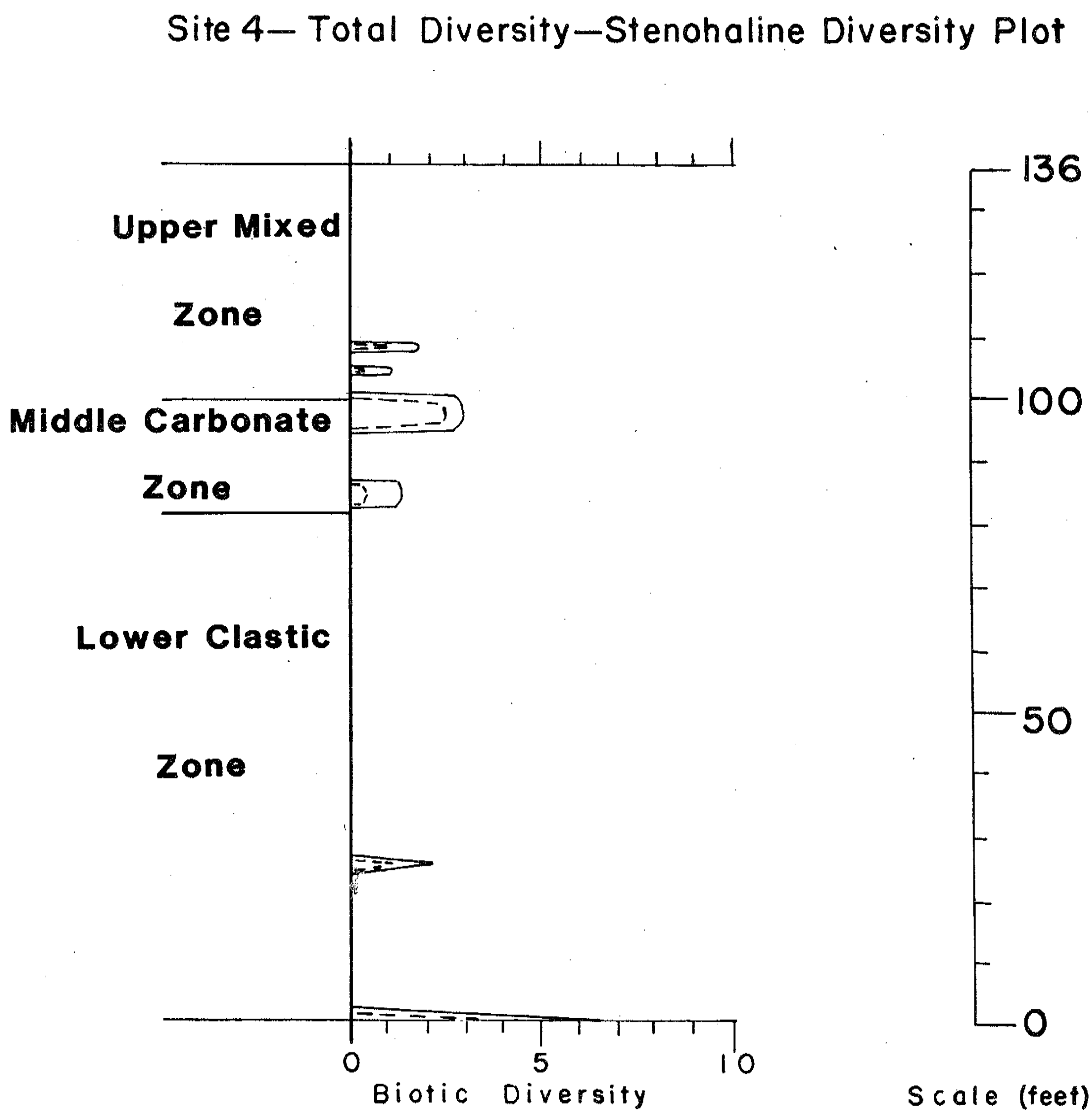


Figure 55: Biotic diversity plot for site 4. Solid line represents total diversity and dashed line represents stenohaline diversity. Moving averages are used to smooth peaks.

APPENDIX H (continued)

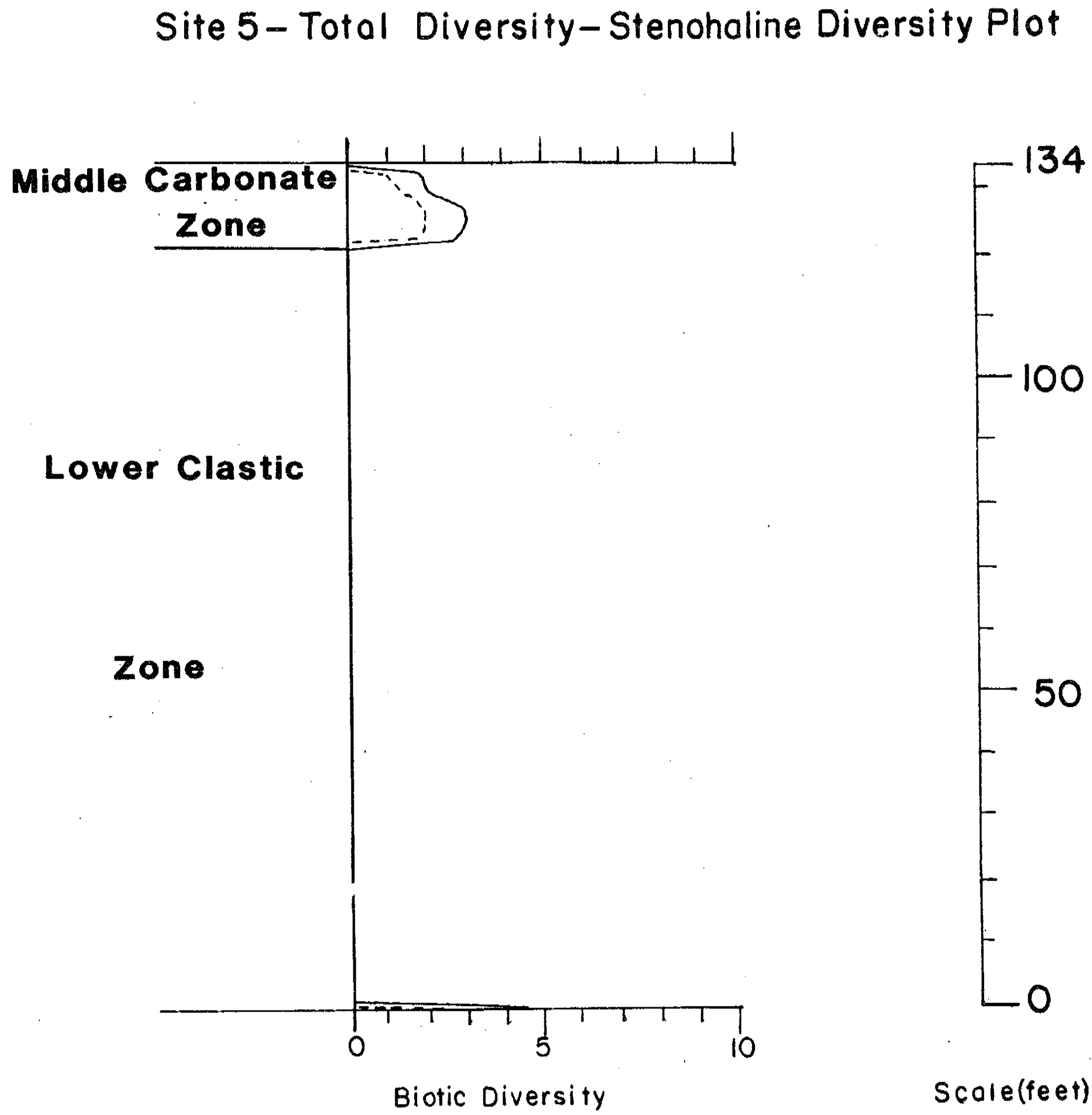


Figure 56: Biotic diversity plot for site 5. Solid line represents total diversity and dashed line represents stenohaline diversity. Moving averages are used to smooth peaks.

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