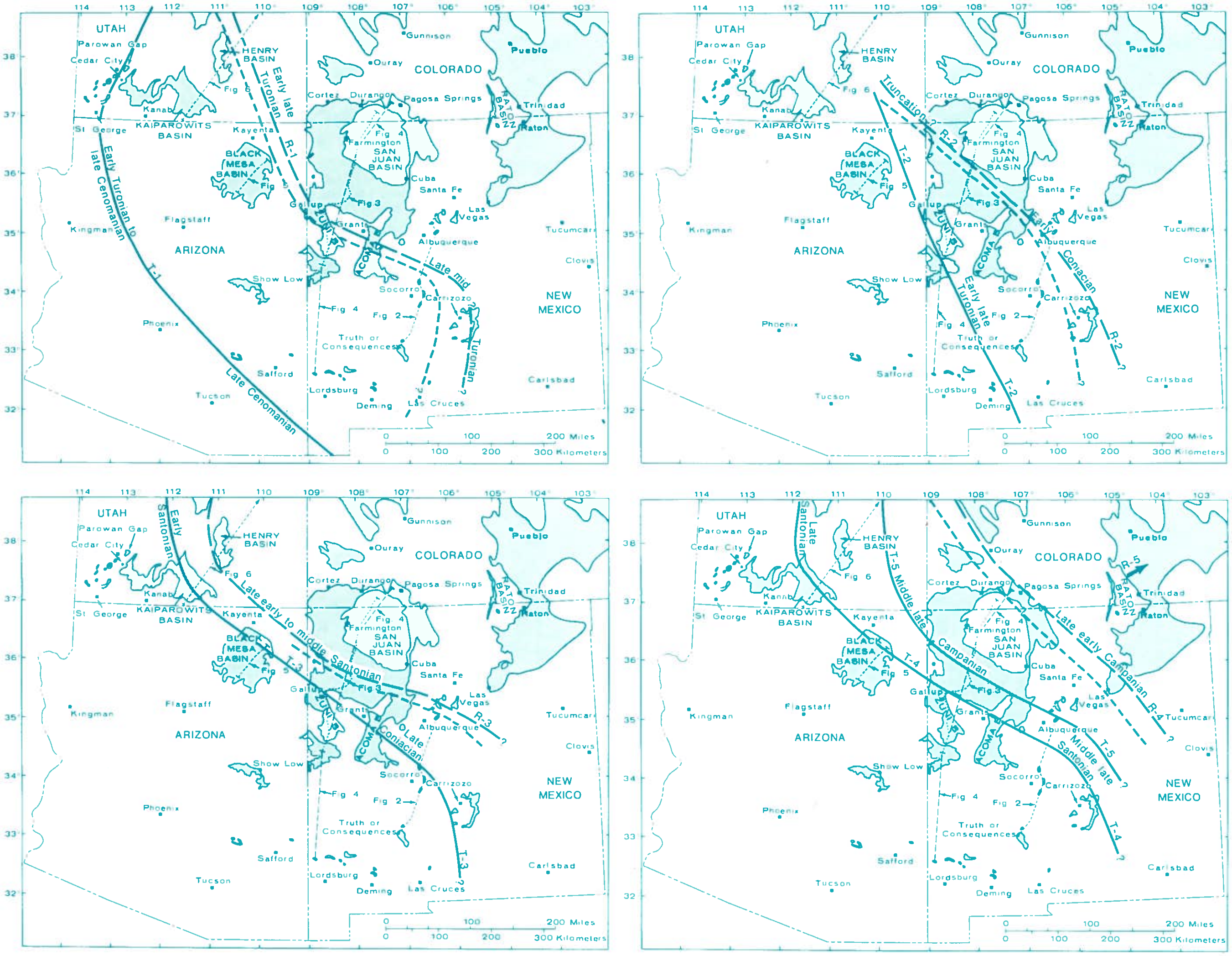
Contributions to Late Cretaceous paleontology and stratigraphy of New Mexico
Part I

Compiled by Donald L. Wolberg



CIRCULAR 195 New Mexico Bureau of Mines & Mineral Resources 1985

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COVER—Cenomanian-Maastrichtian shorelines. From C. M. Molenaar, 1983, Major depositional cycles and regional correlations of Upper Cretaceous rocks, southern Colorado Plateau and adjacent areas; pp. 201-223 *in* Reynolds, M. W., and Dolly, E.D. (eds.), Mesozoic paleogeography of west-central United States: Rocky Mountain Symposium 2, The Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Denver, Colorado.

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New Mexico Bureau of Mines and Mineral Resources
Socorro, New Mexico 87801

SOCORRO 1985

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Contents

Adrian Hunt studying the Fruitland, San Juan Basin, 1982.

Preface

This circular is the first in a series devoted to the paleontology and stratigraphy of the Late Cretaceous of New Mexico and adjoining states. The impetus for this series arose from two sources. First, the ever-increasing pace of Cretaceous paleontologic and stratigraphic research in New Mexico has yielded a wealth of significant data on marine and nonmarine rocks and fossils of invertebrates, vertebrates, palynomorphs, and leaves. Second, my esteemed predecessor in the position of Paleontologist at the New Mexico Bureau of Mines and Mineral Resources, Stephen Hook, now with Texaco, encountered much the same "difficulty" with regard to the mid-Cretaceous. Hook's timely response was to initiate a series of circulars entitled *Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico.* As is obvious, I freely borrowed his idea in formulating the present series. The mid-Cretaceous circulars encompassed the Albian, Cenomanian, and Turonian. More by chance than design, the present series will cover chiefly the Turonian–Maastrichtian interval. Because of where in the section most people seem to be working, it is probable that the majority of the reports will deal with the Turonian and later ages; there will not be much overlap with the mid-Cretaceous of Hook.

Upper Cretaceous rocks in New Mexico and adjoining states contain very significant reserves of coal and, potentially, of hydrocarbons. In addition, Upper Cretaceous deposits have provided resources such as "clinker" for road mettle and calcium carbonate for lime.

The papers included in this circular cover two topical areas—Upper Cretaceous stratigraphy and depositional environments in the San Juan Basin, and Cretaceous selachians.

The paper by Hutchinson and Kues grew out of Hutchinson's thesis at the University of New Mexico, completed under Kues' supervision. It deals with depositional environments and paleontology of the Lewis Shale through lower Kirtland Shale stratigraphic sequence in the San Juan Basin.

Lehman's paper treats the stratigraphic relationships, depositional environments, and paleontology of the Naashoibito Member of the Kirtland Shale in the San Juan Basin. It is a significant contribution to San Juan Basin studies and will encourage a good deal of discussion.

Lucas, Reser, and I report on an interesting selachian discovery from the Pierre Shale in northeastern New Mexico. Finally, I report on a large selachian fauna of Turonian age from a locality in Socorro County, discovered by Bruce Baker during fieldwork for his thesis at New Mexico Tech.

It is interesting and important to note the very real contribution made by graduate students in three of these papers. In these times of economic difficulty in education, the adequate training of graduate students has become seriously impaired. Yet, as is demonstrated in this circular, graduate research is of fundamental importance to the continued progress of scientific inquiry. For its part, the New Mexico Bureau of Mines and Mineral Resources, which functions as New Mexico's geological survey, continues to support and encourage geologic studies by graduate students and professionals related to the State's need for adequate data.

I wish to thank Frank E. Kottlowski, NMBM&MR Director, for continued support; Jiri Zidek, NMBM&MR Chief Editor/Geologist, for enthusiasm and care in editing the papers; Michael Wooldridge and Teresa Mueller for drafting; and Lynne McNeil and Lisa Zangara for typing. Lynne deserves special credit for putting up with my feeble penmanship.

Donald L. *Wolberg*

"When it is therefore borne in mind, that coal and other valuable minerals were not indiscriminately distributed through the earth, but were mainly formed or deposited, at least in quantities and under conditions to be useful to man, during particular geological periods, the importance of knowing to what epoch of the earth's history the rocks of any given district belong, before undertaking mining enterprises of any kind, will be readily understood, and the intelligent general reader will at once comprehend why it is that geologists give so much attention to fossils. In short, the first and most important step in the prosecution of a geological survey, is a careful and thorough study and investigation of the organic remains found in every seam and stratum of the rocks of the district to be explored; for without a knowledge of these, all conclusions in regard to the geological structure of the country, or of the age and position in the geological column of its rocks, must necessarily be vague and unreliable. Indeed, without the aid of Palaeontology, Geology would scarcely be entitled to rank as a science at all."

(From F. B. Meek & A. H. Worthen, 1866,
Geological Survey of Illinois, Vol. 11,
Palaeontology, pp. iv, v.)

Selachians from the Atarque Sandstone Member of the Tres Hermanos Formation (Upper Cretaceous: Turonian), Sevilleta Grant near La Joya, Socorro County, New Mexico

by Donald L. Wolberg
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Abstract

While studying rocks of the Atarque Member of the Tres Hermanos Formation on the Sevilleta Grant, near La Joya, Socorro County, New Mexico, Bruce Baker discovered a series of fossil-rich lenses that have yielded an abundance of selachian teeth and other vertebrate material. Collateral invertebrate data indicate a Turonian age for the deposits. To date nineteen selachian taxa have been identified from these lenses: *Hybodus* sp., *Ptychodus whipplei, P. anonymus, P. polygyrus, Squalicorax falcatus, Cretolamna appendiculata, Cretodus semiplicatus, Chiloscyllium greeni, Scapanorhynchus raphiodon, Anomotodon* sp., *Odontaspis parvidens, 0. macrota, Plicatolamna arcuata, Paranomotodon* sp., *Rhinobatos* sp., *Ischyrhiza avonicola, I. mira, Ptychotrygon triangularis,* and "Batoids indet." *(?Rhombodus).*

Almost all of these taxa represent first reported occurrences in New Mexico, although unreported collections likely exist in the state. This fauna compares favorably with selachian faunas known from elsewhere in the Western Interior and indicates that the biota inhabiting the Western Interior seaway were rather uniform in composition. Several of the reported taxa from the Atarque Member have a cosmopolitan distribution, reflecting the ease of migration in the Cretaceous world. This wide distribution suggests the possibility of stratigraphic and paleoenvironmental applications of selachian faunas. The New Mexico record offers the possibility of establishing a selachian biostratigraphic zonation for the entire Upper Cretaceous.

Introduction

Cretaceous fish faunas of North America are still poorly known (Applegate, 1970). Selachians, although not uncommonly found in Cretaceous rocks, are especially poorly understood and in need of extensive study (Cappetta, 1973). Very little work on New Mexico Cretaceous selachians has been published, although as early as in 1858 Marcou described *Ptychodus whipplei* from the state.

While conducting a geologic study of Upper Cretaceous rocks exposed on the Sevilleta Grant, near La Joya, Socorro County, New Mexico (Fig. 1), Bruce Baker discovered a series of fossil-rich lenses in sandstones of the lower part of the Tres Hermanos Formation (Baker, 1981). Baker and Wolberg (1981) provided a preliminary report of the vertebrates found in the lenses and Wolberg (1985) briefly described the fauna. More than 1300 ft of Upper Cretaceous rocks overlie shales of the Dockum Formation (Upper Triassic) on the Sevilleta Grant, and consist largely of shales and sandstones that include units from the Dakota Sandstone through the Crevasse Canyon Formation (Baker and Wolberg, 1981). The Tres Hermanos Formation overlies the Rio Salado tongue of the Mancos Shale and underlies the D-Cross Tongue of the Mancos Shale. The fossil-rich lenses that yielded the selachians described in this paper are found in the middle part of the Atarque Sandstone Member, the basal unit of the Tres Hermanos Formation (Fig. 2). The stratigraphic nomenclature for the region has been revised by Hook et al. (1983). In the Sevilleta Grant, the Atarque Sandstone Member varies in thickness from 11 to 42 ft and can be divided into lower, middle, and upper parts. The basal Atarque consists of light-gray, fine-grained calcareous sandstones; the middle Atarque consists of yellowish-orange, fine-grained, thinly bedded calcareous sandstone with shale partings; and the upper Atarque consists of very fine-grained, grayish-orange sandstones (Baker, 1981).

Selachians are very abundant in lenses within the middle part of the Atarque. In addition to selachian fossils, turtle-shell fragments, crocodile armor and teeth, plesiosaur teeth, and mollusk-shell fragments

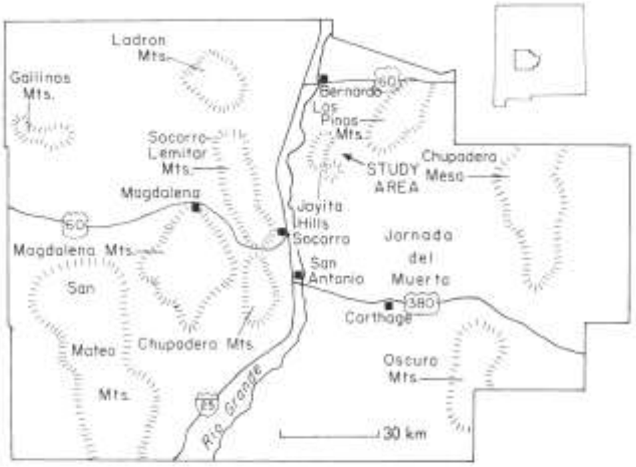

FIGURE 1—Location map of study area (after Baker, 1981).

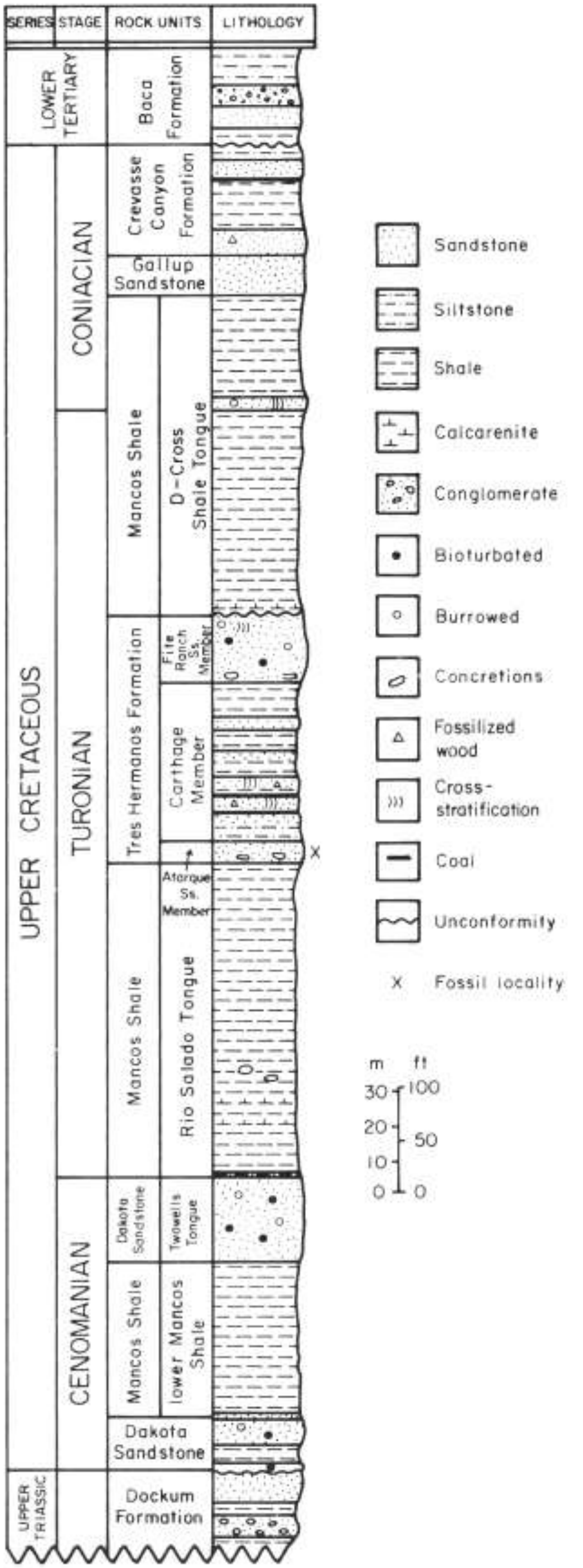

FIGURE 2—Stratigraphic column of the Sevilleta Grant, Socorro County, New Mexico (after Baker, 1981).

cemented by carbonate have been recovered. The plesiosaur material will be described elsewhere. Vertebrate specimens were recovered by breaking down the rock matrix with dilute acetic and formic acids followed by washing, screening, and drying the resultant concentrate. Specimens were then picked with and without the use of a binocular microscope. The classification scheme used generally follows Romer (1966), Cappetta (1973), Herman (1975), Cappetta and Case (1975), and Cappetta (pers. comm.).

The terminology used in the descriptions below largely follows Cappetta (1973 and elsewhere) and in part Herman (1975), although the descriptive terminology for *Hybodus* follows Johnson (1981). Selachiantooth descriptive terminology is not well defined (see Thurmond and Jones, 1981, for example). In general, teeth were oriented as discrete elements without regard to possible placement in the jaws and no attempt was made to reconstruct dentitions. Thus terms such as anterior and posterior, primary and secondary cusp, cusp apex, etc., although artificial, can be related to features present on each tooth and are largely self-evident.

The entire suite of the La Joya fossils is deposited in the New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) paleontological collection. Only numbers of illustrated specimens are included in this paper because the collection is quite large and will eventually receive catalogue numbers for dentitions rather than individual teeth.

Acknowledgments—Bruce Baker discovered the locality that yielded the specimens described in this paper during the conduct of his graduate research at New Mexico Institute of Mining and Technology. With the assistance of Stephen C. Hook, Texaco, Inc., Baker securely placed the locality within a stratigraphic context. Peter Robinson provided access to the Michael Evetts collection of selachian teeth from the Turonian Turner Sandy Member of the Carlile Shale in South Dakota, and to other material reposited in the paleontology collections of the University of Colorado, Boulder. Robert E. Sloan and Joseph Hartman, University of Minnesota, provided comparative material from Cretaceous deposits in northern Minnesota. Wayne Wentworth and Shannon Krause assisted with acid-etching of the rock matrix. Michael Wooldridge and Teresa Mueller provided drafting assistance. Jiri Zidek, New Mexico Bureau of Mines and Mineral Resources, provided useful suggestions and critical comments for improving the manuscript. Henri Cappetta, Laboratory of Paleontology, Montpellier, France, critically read an earlier draft of this paper. His comments and suggestions are appreciated. This research was supported by the New Mexico Bureau of Mines and Mineral Resources.

Systematicpaleontology

Class CHONDRICHTHYES
Subclass ELASMOBRANCHII
Order SELACHII
Suborder HYBODONTOIDEA
Family HYBODONTIDAE Owen, 1846
Genus *HYBODUS* Agassiz, 1837
HYBODUS sp.
Fig. 3/9

Description—Hybodus sp. is represented by incomplete specimens of comparatively small size. Typically, the principal cusp is triangular with a blunt apical tip. The principal cusp flares laterally at its base with a suggestion of a secondary cusp. Short striations are developed basally; they do not extend up the principal cusp labially, but do so lingually. A trenchant longitudinal occlusal crest emarginates the cusp in profile view (terminology after Johnson, 1981). Root morphology is not preserved in the collection.

Discussion—Hybodus is a common Mesozoic genus and is known from the Triassic–Cretaceous in North America (Romer, 1966). The New Mexico specimens are very similar to *Hybodus* described from the Upper Cretaceous of Delaware (Lauginiger and Hartstein, 1983).

Suborder HETERODONTOIDEI
Family PTYCHODONTIDAE Woodward, 1912
Genus *PTYCHODUS* Agassiz, 1839
PTYCHODUS WHIPPLEI Marcou, 1858
Fig. 3/1-4

1858. *Ptychodus whipplei* Marcou, p. 33, pl. 1, fig. 4.
1873. *Ptychodus whipplei* Marcou: Leidy, p1. XVIII, figs. 19, 20.
1900. *Ptychodus whipplei* Marcou: Williston, p. 243, pl. 29, figs. 1015.
1973. *Ptychodus whipplei* Marcou: Cappetta, p. 505, pl. 1, figs. 1-6.
1976. *Ptychodus whipplei* Marcou: Edwards, p. 67, fig. la.
1979. *Ptychodus whipplei* Marcou: Evetts, p. 61, pl. 1, figs. 6-12, 6'-12'.

Description—The crown is raised, conical, and its longitudinal axis is oblique with respect to the root. In occlusal view, the teeth exhibit a regular outline that is anteriorly convex and posteriorly concave. The apex of the crown bears ridges that extend to merge with the basal ornamentation of crenulated and rugose enamel. The base of the crown markedly overhangs the root. The root is low, blocky, with an anteroposteriorly oriented depression.

Discussion—Ptychodus *whipplei* is a very distinctive taxon; except for *P. anonymus,* it is not easily confused with other species of *Ptychodus.* Both taxa are distinguished by raised crowns. Distinguishing features of *P. anonymus* are indicated below. *P. whipplei* was first named from the Cretaceous of New Mexico: Marcou (1853: 33) reported *P. whipplei* from "the gray sandy marls, three miles north of Galisteo, on the road from Galisteo to Pecos, New Mexico." Although the genus has a cosmopolitan distribution, *P. whipplei* seems to be restricted to the Upper Cretaceous of North America and is not uncommon.

PTYCHODUS ANONYMUS Williston, 1900
Fig. 3/6-8

1900. *Ptychodus anonymus* Williston, p. 241, pl. 29, figs. 5-8, 1618, 20-22, 24.
1968. *Ptychodus* cf. *P. whipplei* Marcou: Bardack, p. 146, pl. 1, fig. 2.
1979. *Ptychodus anonymus* Williston: Evetts, p. 61, pl. 1, figs. 2-4, 2'-4'.

Description—Crown broad, gently conical, anteroposteriorly elongate, with reticulate ornamentation on crown. Ridges across apex do not extend to crown base; base strongly convex anteriorly in occlusal view; deep concave notch posteriorly.

Discussion—Both *P. anonymus* and *P. whipplei* display strongly raised apical crowns. However, the crown of *P. anonymus* is more elongated and less acutely conical. Like *P. whipplei, P. anonymus* is restricted to the Upper Cretaceous of North America, and was originally described by Williston (1900) from the "Benton" and "Niobrara" of Kansas. I concur with Evetts (1979) that the specimen figured by Bardack (1968) from the Boyne Member of the Vermillion River Formation in Manitoba, Canada, can be referred to *P. anonymus.* It is likely that *P. whipplei* and *P. anonymus* are closely related.

PTYCHODUS POLYGYRUS Agassiz, 1843
Fig. 3/5

1843. *Ptychodus polygyrus* Agassiz, p. 156, pl. 25, figs. 4-11, pl. 25b, figs. 21-23.
1900. *Ptychodus* sp.: Williston, p. 243, pl. 29, figs. 2, 3, p1. 31, fig. 53.
1911. *Ptychodus polygyrus* Agassiz: Woodward, p. 232, pl. 48, figs. 12-16.
1979. *Ptychodus polygyrus* Agassiz: Evetts, p. 62, pl. 1, figs. 5, 51.

Description—Massive teeth with gently arcuate, broadly raised crown; prominent occlusal transverse ridges medially straight and distally arcuate. Margins of crown coarsely reticulated. The teeth are convex anteriorly and straight to subconcave posteriorly in occlusal view.

Discussion—Ptychodus *polygyrus* is a cosmopolitan species known from the Turonian through Santonian of the English Chalk (Woodward, 1911), the "Niobrara" of Kansas (Williston, 1900), and the Selma Group of Alabama (Applegate, 1970). *P. polygyrus* is also known from Belgium and the U.S.S.R.

The abundant and diverse representation of ptychodonts in the Atarque fauna clearly reflects the abundance of mollusks that formed the food source for these selachians.

ORDER LAMNIFORMES
Suborder LAMNOIDEI
Family ANACORACIDAE Casier, 1967
Genus *SQUALICORAX* Whitley, 1939
SQUALICORAX FALCATUS (Agassiz, 1843)
Fig. 6/5-6

1843. *Corax falcatus* Agassiz, p. 226, pl. 26, fig. 14, pl. 26a, figs. 1-15.
1852. *Oxyrhina* zippei? Agassiz: Gervais, pl. 76, fig. 16.
1852. *Corax appendiculatusa* Agassiz: Gervais, pl. 76, fig. 17.

1873. *Galeocerdo falcatus* (Agassiz): Leidy, pp. 301, 302, pl. XVIII, figs. 29, 30, 32, 37-39, 42.
1900. *Corax falcatus:* Williston: p. 252, pl. 31, figs. 1-40, pl. 32, figs. 1-11.
1902. *Corax falcatus* Agassiz: Leriche, pl. IV, figs. 76-78. 1907.
Corax falcatus Agassiz: Priem, pp. 463-465, figs. 3, 6. 1911.
Corax falcatus Agassiz: Fowler, p. 63, fig. 28.
1911. *Corax falcatus* Agassiz: Woodward, p. 198, pl. 42, figs. 16-28.
1927. *Corax baharijensis* Stromer, pl. I, figs. 26, 27.
1935. *Corax falcatus* Agassiz: Dalinkevichius, pl. III, figs. 63-67.
1935. *Corax falcatus* Agassiz: Arambourg, p. 428, pl. 19, fig. 9.
1936. *Corax falcatus* Agassiz: Leriche, pp. 381, 382, pl. 26, figs. 5, 6.
1943. *Anacorax falcatus* (Agassiz): Dartevelle and Casier, pl. I, figs. 1-6.
1959. *Anacorax falcatus* (Agassiz): Dartevelle and Casier, pl. XXIV, figs. 1-9.
1964. *Palaeocorax falcatus* (Agassiz): Glikman, pl. III, figs. 7, 8.
1969. *Squalicorax falcatus* (Agassiz): Bilelo, p. 343, fig. 2. 1970.
Squalicorax falcatus (Agassiz): Applegate, p. 396, figs. L, N. 1973.
Squalicorax falcatus (Agassiz): Cappetta, p. 506, pl. 1, figs. 17-27.
1976. *Squalicorax falcatus* (Agassiz): Edwards, p. 67, fig. la.
1979. *Squalicorax falcatus* (Agassiz): Evetts, pl. 1, figs. 38-47.

Description—Trenchant teeth with very compressed main blade in which height exceeds width. The blade is roughly triangular and serrated, and its apex converges to a point. When preserved, the main blade is separated from posterior lobe and its denticle by a deep notch. The root is not markedly deep, but is well developed, with numerous foramina. Anterior curvature of the blade is more sigmoidal than arcuate, with apical portion directed anteriorly. The attitude of the blades varies with respect to the plane of the root; the apical distance to the root plane varies inversely with the degree of blade slope.

Discussion—The trenchant teeth of S. *falcatus* are easily recognized. Bilelo (1969) discussed the genus *Squalicorax* in north-central Texas. Leriche (1939) reported S. *kaupi* from the Coniacian, Santonian, and early Campanian of Africa.

S. falcatus is known from the Turonian of Texas (Bilelo, 1969), South Dakota (Cappetta, 1973), and New Mexico. It is also known from the Cenomanian, Santonian, and Campanian of Europe (Priem, 1912).

S. pristodontus (Agassiz) ranges from the late Santonian to the end of the Maastrichtian, although a pre-Campanian age may be questioned on geological grounds (Bilelo, 1969). S. *pristodontus* has a cosmopolitan distribution. Despite a stratigraphic overlap, the *S. kaupi-S. falcatus-S. pristodontus* sequence forms a suitable evolutionary series. The wide geographic distribution of these taxa enhances their stratigraphic utility.

Squalicorax falcatus is not abundantly represented in the Joyita Hills fauna, but is not particularly rare either. By contrast, Lauginiger and Hartstein (1983) report that *S. kaupi* is the most commonly found Delaware selachian. At La Joya, no complete specimens have been recovered as yet. The trenchant, serrated teeth of *S. falcatus* show that it was an active predator.

Order GALEIFORMES
Suborder ISUROIDEI
Family ISURIDAE Garman, 1813
Genus *CRETOLAMNA* Glikman, 1958
CRETOLAMNA APPENDICULATA (Agassiz, 1835)
Fig. 6/10-17

1835. *Lamna appendiculata* Agassiz, p. 54.
1843. *Otodus appendiculatus* Agassiz, p. 270, pl. 32, figs. 1-25.
1910. *Lamna appendiculata* Agassiz: Woodward, p. 206, pl. 44, figs. 3-7.
1900. *Lamna appendiculata* Agassiz: Williston, p. 247, pl. 26, fig. 3, pl. 31, figs. 47-49.
1970. *Lamna appendiculata* Agassiz: Applegate, p. 396, fig. 178 e—h. 1975. *Cretolamna appendiculata* (Agassiz, 1843): Cappetta and Case, p. 21, pl. 3, figs. 10-28.
1979. *Lamna appendiculata* Agassiz: Evetts, p. 63, pl. 1, figs. 38-47.
1981. *Lamna appendiculata* Agassiz: Witzke, p. 108, pl. 1, figs. 1420.

Description—Substantial, robust teeth with massive, basally bilobed roots that are deeply arcuate, with prominent median concavity. Primarily triangular cusp with minor anterior and posterior denticles, also triangular in form. Primary cusp frequently found with broken tips, essentially vertical to posteriorly inclined in lateral teeth. Leading and posterior edges of cusps trenchant. Cusps vary in width depending on placement in the jaws.

Discussion—Cretolamna appendiculata is of cosmopolitan distribution and occurs in rocks of Cenomanian to late Paleocene age.

The family Isuridae (Lamnidae in older literature) includes the Mackerel sharks and consists of large, voracious fish with lunate caudal fins. The Mackerel sharks are aggressive predators and include the modern Great White, *Carcharodon carcharias* (Linnaeus), as well as modern representatives of the genus *Lamna.* They are generally found near the surface and feed on fish, including other sharks, marine reptiles, and mammals.

CRETODUS SIMPLICATUS (Agassiz, 1843)
Fig. 3/10-21

1843. *Otodus semiplicatus* Agassiz, p. 272, pl. 36, figs. 32, 33.
1873. *Otodus divaricatus* Leidy, pl. XVIII, figs. 26-28.
1902. *Otodus sulcatus* Geinitz: Leriche, pl. III, fig. 48.
1910. *Oxyrhina crasidens* Dixon: Woodward, pl. XLIV, figs. 1, 2.
1910. *Lamna semiplicata* (Agassiz): Woodward, pl. XLIV, figs. 10, 11.
1910. *Lamna sulcata* Geinitz: Woodward, pl. XLIV, figs. 12, 13. 1935. *Lamna* cf. L. *semiplicata* (Agassiz): Dalinkevichius, pl. V, figs. 110, 111.
1936. *Lamna semiplicata* (Agassiz): Leriche, pl. XXIV, figs. 1-4.
1938. *Scapanorhynchus(?)* sp.: Leriche, p. 23, pl. IV, figs. 25, 25', 25a.
1973. *Lamna semiplicata* (Agassiz): Cappetta, p. 506, pl. 1, figs. 7, 7'.
1979. *Lamna semiplicata?* (Agassiz): Evetts, p. 63, pl. 1, figs. 48, 48'.

Description—Cretodus *semiplicatus* is very similar to *Cretolamna appendiculata.* The primary distinguishing feature seen in the teeth of this taxon is the presence of short, vertically oriented striae on the inner and outer base of the primary blade or cusp.

Discussion—As noted by Cappetta (1973), *Cretodus semiplicatus* is known from Europe, where it is found in rocks of Cenomanian to Turonian age. It also is known from the late Turonian of Angola. Evetts (1979) and Cappetta (1973) report the taxon from the Carlile Shale of South Dakota. Both *Cretodus semiplicatus* and *Cretolamna appendiculata* are about equally represented in the Atarque fauna.

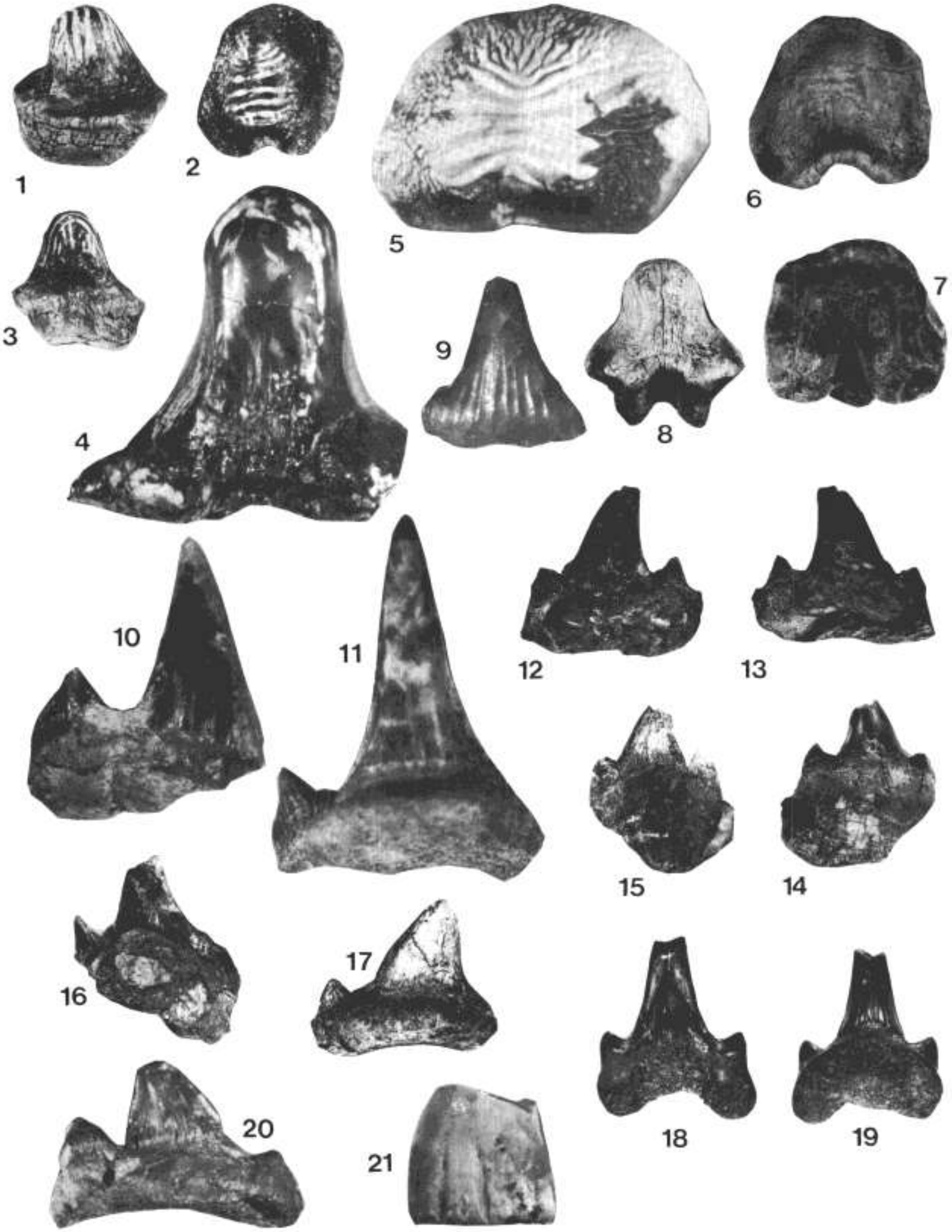

FIGURE 3—*Ptychodus, Hybodus, Cretodus,* and *Ischyrhiza* from the Turonian at the Sevilleta Grant. **1–3,** No. B-0131, *Ptychodus whipplei* Marcou, lateral (1), occlusal (2), and posterior (3) views, ×2.5. **4,** No. B-0123, *Ptychodus whipplei* Marcou, ×5. **5,** No. B-0148, *Pychodus polygyrus* Agassiz, occlusal view, ×5. **6–8,** No. B-0130, *Ptychodus anonymus* Williston, occlusal (6) and ventral (7) views, ×2.5, and posterior (8) view, ×2. **9,** No. B-0009, *Hybodus* sp., lateral view, ×12. **10,** No. B-0162, *Cretodus semiplicatus* (Agassiz), ×5. **11,** No. B-0165, *C. semiplicatus,* ×5. **12, 13,** No. B-0142, *C. semiplicatus,* ×1.5. **14, 15,** No. B-0116, *C. semiplicatus,* ×2. **16,** No. B-0115, *C. semiplicatus,* ×2. **17,** No. B-0132, *C. semiplicatus,* ×2. **18, 19,** No. B-0113, *C. semiplicatus,* ×2. **20,** No. B-0017, *C. semiplicatus,* ×4. **21,** No. B-0175, *Ischyrhiza mira* Leidy, ×5.

Family ORECTOLOBIDAE Gill, 1895
Genus *CHILOSCYLLIUM* Muller and Henle, 1841
CHILOSCYLLIUM GREENI (Cappetta, 1973)
Fig. 5/1, 2

1973. *Brachaelurus greeni* Cappetta, p. 507, pl. 1, figs. 36-41.
1975. *Mesiteia? greeni* (Cappetta): Herman, p. 146, pl. 6, fig. 2.

Description—Very small teeth with little variation in morphology. A prominent, triangular main cusp is flanked by a weakly developed, low, and relatively blunt anterior and posterior cuspule. The enamel is smooth and unornamented. The cuspules are poorly separated from the main cusp by a shallow concavity. Basally, the entire crown overhangs the root in an enamel apron that is strongly arcuate. The crown is strongly recumbent and posteriorly concave. The root is broad and bilobed. In basal view, a major foramen is evident.

Discussion—Described by Cappetta (1973) from the Carlile Shale, *Chiloscyllium greeni* is easily distinguished by its very small size, smooth, unornamented enamel, and anterior and posterior denticles flanking the primary cusp. The present occurrence is only the second report of the species and the first record from New Mexico. Cappetta (1973) suggests that *C. greeni* may be ancestral to *Squatirhina.*

The family Orectolobidae includes the modern Nurse sharks, Leopard sharks, and Catsharks. They are small to medium-sized sharks that are benthic, coastal-dwelling forms now found in the warmer waters of the Indo-Pacific. The genus *Chiloscyllium,* the Cat-shark, is characterized by strongly developed markings.

Family MITSUKURINIDAE Jordan, 1898
Genus *SCAPANORHYNCHUS* Woodward, 1889
SCAPANORHYNCHUS RAPHIODON (Agassiz, 1843)
Fig. 6/1-4

1843. *Lamna (Odontaspis) raphiodon* Agassiz, p. 296, pl. 37a, figs. 11-16.
1900. *Scapanorhynchus raphiodon* (Agassiz): Williston, p. 251, pl. 26, fig. 4, pl. 32, fig. 5.
1910. *Scapanorhynchus raphiodon* (Agassiz): Woodward, p. 211, pl. 44, figs. 14-17.
1970. *Scapanorhynchus raphiodon* (Agassiz): Applegate, p. 395, fig. 178a—c.
1979. *Scapanorhynchus raphiodon* (Agassiz): Evetts, p. 63, pl. 1, figs. 13-17, 37.
1981. *Scapanorhynchus* sp.: Witzke, p. 108, p1. 1, figs. 8-13.

Description—Distinguished by a relatively slender and long blade atop a strongly arcuate and bilobate root. A prominent concavity is located medially on the root. In profile, the root shows a flat interior face. The blade is distinctively recurved. The inner surface is convex, while the external surface is flat. The apical tip is sharply pointed. Internally, the blade is ornamented with fine vertical striae.

Discussion—Scapanorhynchus raphiodon is of cosmopolitan distribution. Some confusion exists in differentiating between *S. raphiodon* and *S. texanus* (see Cappetta and Case, 1975). It may be that *S. raphiodon* is ancestral to *S. texanus.*

Scapanorhynchus is included with the Goblin sharks. It was thought that *Scaponorhynchus* was the sole representative, known only from fossils, of the family *Scapanorhynchidae,* but in 1898 *Mitsukurina owstoni* was taken from great depths in the Pacific Ocean near Japan. Since then, the modern species has been recorded from Portugal, French Guyana, South Africa, Australia, and the Gulf of Gascogne, France (Cappetta, pers. comm.).

Genus *ANOMOTODON* Arambourg,
1952 *ANOMOTODON* sp.
Fig. 6/7-9

Description—Very distinctive teeth with thin profile and stout bilobed root. The primary cusp is bladelike, slender and relatively long, with rounded apical tip. The blade lacks striae or accessory cuspules. The root is distinctive, with flared, rounded distal borders that flatten in profile. A constricted medial groove is present in lingual view; the root has a prominent "shoulder" lingually. The blade is flattened labially but convex lingually.

Discussion—This genus is present in the Cretaceous of Morocco (Arambourg, 1952) and Germany. Cappetta (1976) and Case (1980) noted the similarity of *Anomotodon* to *Scapanorhynchus* and included the genus in the Mitsukurinidae. In morphology, a strong resemblance is seen to *Scapanorhynchus rapax,* but vertical striae are absent. The Atarque specimens may represent a new species of *Anomotodon,* but more material is needed to ascertain this.

Family ODONTASPIDAE Muller and Henle, 1841
Genus *ODONTASPIS* Agassiz, 1838
ODONTASPIS PARVIDENS Cappetta, 1973
Fig. 4/7, 8

1973. *Odontaspis parvidens* Cappetta, p. 507, pl. 3, figs. 1-7.

Description—This species is characterized by small size, a feature for which it is named, with a relatively high triangular main cusp flanked anteriorly and posteriorly by small, pointed denticles present in lateral teeth, but absent in anterior teeth. The root is relatively massive, with a well-developed nutritive groove. The main cusp shows a sigmoid flexure with a re-curved apical tip, to an arcuate form with the apical-cusp regions almost recumbent. In profile, the root is posteriorly flattened.

Discussion—This species was named by Cappetta (1973). It is distinguished from other species of the genus by its small size and root morphology. The Joyita Hills specimens are only the second known occurrence of the species. *0. parvidens* is a common element of the fauna.

The family Odontaspidae (Carchariidae in older literature) comprises the Sand sharks. Odontaspids are primarily medium-sized sharks that inhabit shallow waters. They are active swimmers and feed on fish, crustaceans, and cephalopods.

ODONTASPIS MACROTA (Agassiz, 1843)
Fig. 4/3, 4, 9-11

1843. *Lamna (Odontaspis) macrota* Agassiz, v. 3, p. 373, pl. 32, figs. 29-31.

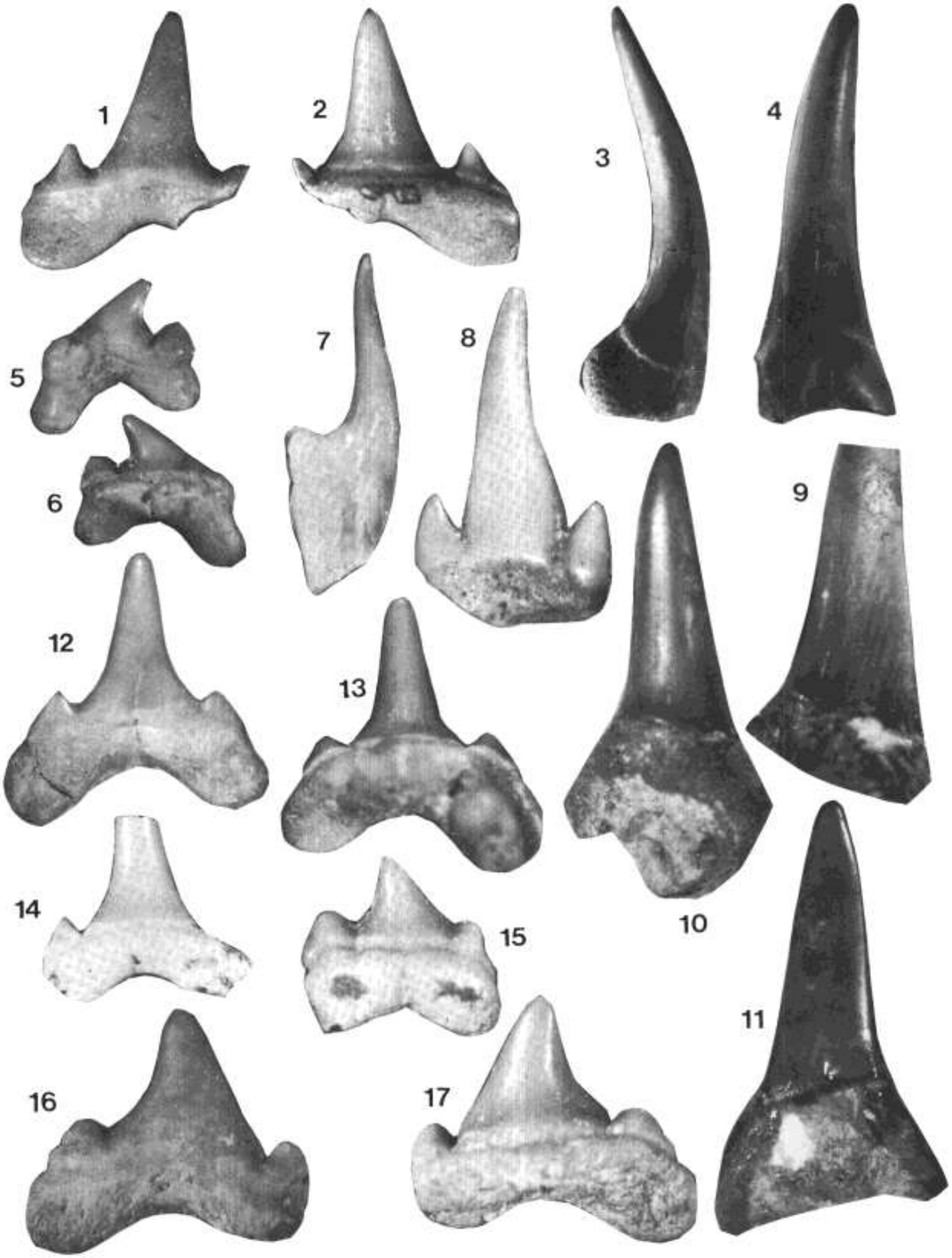

FIGURE 4—*Plicatolamna* and *Odontaspis* from the Turonian at the Sevilleta Grant. **1, 2,** No. B-0031, *Plicatolamna arcuata* (Woodward), ×6.5. **3, 4,** No. B-0158, *Odontaspis macrota* Agassiz, profile (3) and lateral (4) views, ×6.5. **5, 6,** No. B-0170, *Plicatolamna arcuata* (Woodward), ×6.5. **7,** No. B-0151, *Odontaspis parvidens* Cappetta, profile view, ×16. **8,** No. B-0003, *Odontaspis parvidens* Cappetta, outer face, ×16. **9–11,** No. B-0153, *Odontaspis macrota* Agassiz, lateral views (10, 11), ×4, and a ×6.5 enlargement (9) to show fine serrations. **12, 13,** No. B-0164, *Plicatolamna arcuata* (Woodward), ×8. **14,** No. B-0032, *P. arcuata* (Woodward), ×8. **15,** No. B-0024, *P. arcuata* (Woodward), ×9.5. **16, 17,** No. B-0030, *P. arcuata* (Woodward), ×9.5.

1942. *Odontaspis macrota* (Agassiz): Leriche, p. 44.
1956. *Odontaspis macrota* (Agassiz): White, pp. 147, 148.
1981. *Odontaspis macrota* (Agassiz): Thurmond and Jones, p. 48, fig. 14.

Description—Similar to *Scapanorhynchus raphiodon,* but with less massive roots. Roots are smaller relative to the cusp than in *S. raphiodon.* Accessory cuspules weakly developed. Lingual striations are relatively fine or weakly developed. The main blade is tall, apically recurved and sigmoidal, with trenchant leading edge. There is a constricted medial groove on bilobed root; the medial groove is less well developed than in *S. raphiodon.*

Discussion—This form is similar to *Scapanorhynchus raphiodon,* but with differences as noted above. The species has been reported from Texas and Alabama. Thurmond and Jones (1981) noted that two subspecies may be present: *0. macrota semistriata* and *0. macrota striata.* The La Joya collections do not as yet allow a referral of the New Mexico specimens to a subspecies.

Family CRETOXYRHINIDAE Glikman, 1958
Genus *PLICATOLAMNA* Herman *(in* Cappetta and Case, 1975)
PLICATOLAMNA ARCUATA (Woodward, 1894)
Fig. 4/1, 2, 5, 6, 12-17

1894. *Lamna arcuata* Woodward, p. 198, pl. VI, fig. 10.
1897. *Lamna arcuata* Woodward: Priem, p. 40, pl. 1, figs. 7-11.
1967. *Lamna appendiculata:* Case, p. 11, fig. 57.
1973. *Lamna appendiculata:* Case, p. 20, fig. 63.
1975. *Plicatolamna appendiculata* (Woodward): Herman, p. 203, pl. 8, fig. 4.
1975. *Plicatolamna appendiculata* (Woodward), Cappetta and Case, 1975, p. 23, pl. 4, figs. 1-18.
1983. *Plicatolamna arcuata* (Woodward): Lauginiger and Hartstein, p. 28, pl. 1, figs. 8, 9.

Description—Moderately large teeth with massive, arcuate, bilobed roots and a medial primary cusp. The primary cusp is triangular, externally convex, and in complete specimens is flanked by small, but well-developed, anterior and posterior denticles. Short basal plications are most pronounced externally. In anterior teeth the primary cusp is essentially vertical, whereas in lateral teeth it is inclined. Cusps in upper lateral teeth are not as tall as in lower laterals and the secondary denticles are proportionately larger.

Discussion—Plicatolamna arcuata was recognized as a distinct species by Herman *(in* Cappetta and Case, 1975) from the Campanian of England. It is present also in the Cenomanian of Lithuania, the Campanian of New Jersey and Delaware, and the Campanian and Maastrichtian of Belgium.

Family ALOPIDAE Bonaparte, 1838
Genus *PARANOMOTODON* Herman *(in* Cappetta and Case, 1975)
PARANOMOTODON sp.
Fig. 5/17

Description—Only a single specimen has been recovered. The root appears arcuate below moderately developed triangular cusp. There is no indication of accessory denticles. The cusp is directed posteriorly and is more convex lingually than labially. It is an teriorly convex and posteriorly concave, with trenchant leading and trailing edges and a sharp apex. Basal striae are developed labially and lingually.

Discussion—Paranomotodon is known from the Cenomanian–Santonian of Europe and the Upper Cretaceous of Zaire and Japan. Cappetta and Case (1975) described *Paranomotodon* cf. *angustidens* from the late Campanian of New Jersey.

Paranomotodon is included within the Alopidae, or Thresher sharks. Modern Thresher sharks are distinguished by the extreme development of their caudal fin and are active predators, using their caudal fin to stun prey. Modern Thresher sharks are cosmopolitan; they inhabit predominantly open oceans, but do venture inshore (Castro, 1983).

Order RAJIFORMES
Suborder RHINOBATOIDEI
Family RHINOBATIDAE Muller and Henle, 1841
Genus *RHINOBATOS* Linck, 1790
RHINOBATOS sp.
Fig. 5/16

Description—Very distinctive teeth with low, basically smooth, cap-shaped crown and massive, bulbous root lobes formed by prominent medial sulcus. In occlusal view, the crown is subcircular in outline, with weakly to moderately developed transverse medial ridge or crest. The anterior face is convex and visor-like, with rounded margin.

Discussion—Rhinobatos was reported by Cappetta (1973) from the Turonian of South Dakota. The genus is cosmopolitan during the Cretaceous. A good deal of variation in dental morphology is present, depending on placement of the teeth. In some respects, the La Joya specimens differ from those reported by Cappetta (1973), Cappetta and Case (1975), and Cappetta (1980). It is not possible to refer these specimens to a species of *Rhinobatos* at this time.

Rhinobatos is a moderately sized Guitarfish—sluggish, bottom-living ray common on sandy bottoms. Guitarfish are poor swimmers and frequently conceal themselves beneath the sand. They appear to be broadly tolerant of water conditions and may enter estuaries (Smith, 1953).

Suborder SCLERORHYNCHOIDEI
Family SCLERORHYNCHIDAE Cappetta, 1974
Genus *ISCHYRHIZA* Leidy, 1856
ISCHYRHIZA AVONICOLA Estes, 1964
Fig. 5/9, 10, 22

1964. *Ischyrhiza avonicola* Estes, p. 14, fig. 6.
1968. *Ischyrhiza avonicola* Estes: Slaughter and Steiner, p. 236, figs. K, M.
1973. *Ischyrhiza avonicola* Estes: Cappetta, p. 510, pl. 1, figs. 8-13.

Description—Rostral teeth characterized by post-like or bilobed peduncle with a pyramidal enamel cap. The cap is substantially smaller than the peduncle, compressed in anterior profile but broad and flattened in lateral view. The peduncle is fenestrated and basally concave. Enamel cap may overhang peduncle basally; the cap is inclined rather than vertical.

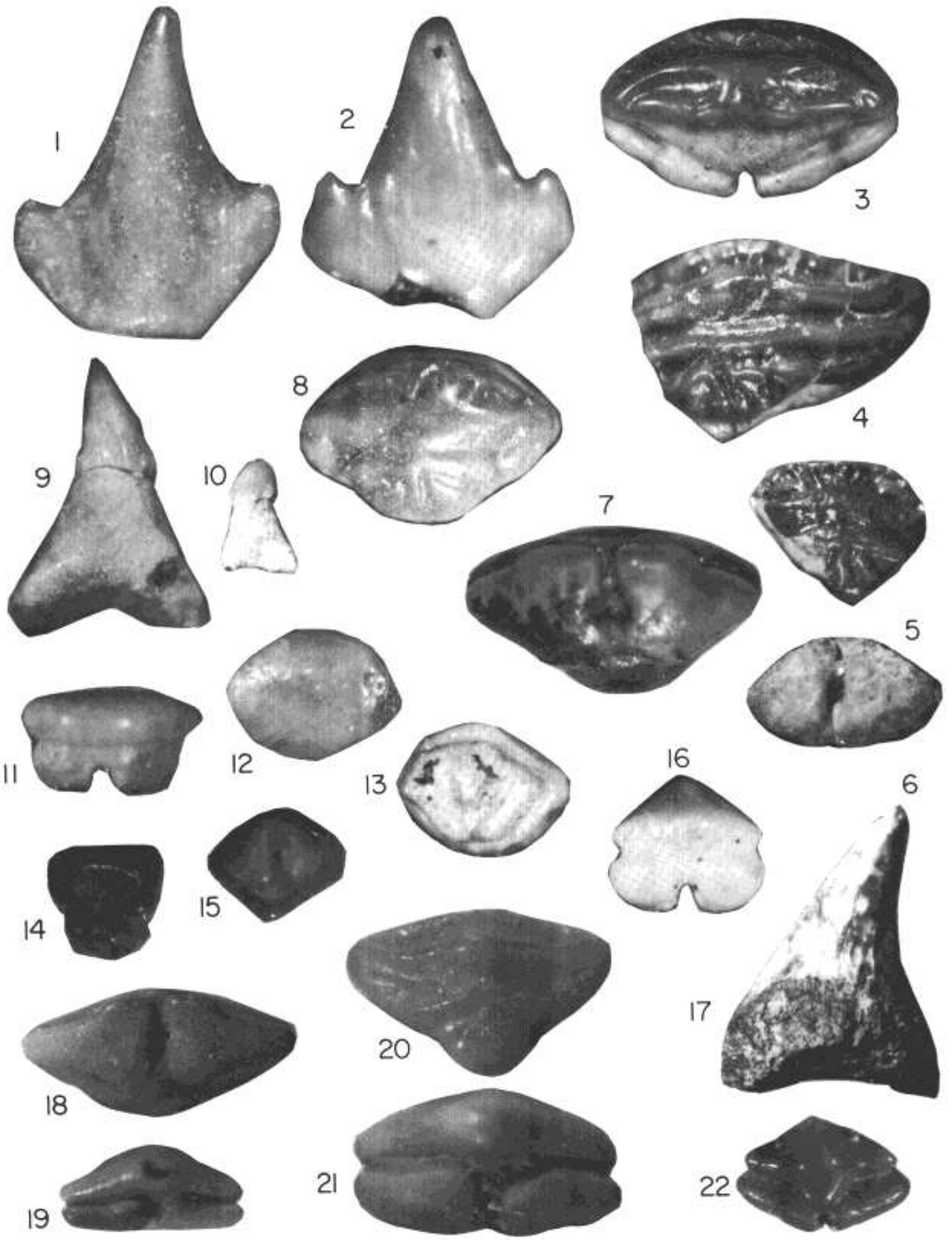

FIGURE 5—*Chiloscyllium, Ptychotrygon, Ischyrhiza,* and Batoids indet. from the Turonian at the Sevilleta Grant. **1,** No. B-0019, *Chiloscyllium greeni* (Cappetta), lateral view, ×19. **2,** No. B-008, *Chiloscyllium greeni* (Cappetta), lateral view, ×19. **3,** No. B-0100, *Ptychotrygon triangularis* (Reuss), tangential view, ×13. **4,** No. B-0173, *P. triangularis,* (Reuss), occlusal view, ×13. **5, 6,** No. B-0171, *P. triangularis,* (Reuss), occlusal (5) and basal (6) views, ×9.5. **7,** No. B-0101, *P. triangularis,* (Reuss); basal view, ×13. **8,** No. B-0169, *P. triangularis,* (Reuss); occlusal view, ×13. **9,** No. B-0175, *Ischyrhiza avonicola* Estes, ×14.5. **10,** No. B-0025, *Ischyrhiza avonicola* Estes, ×14.5. **11–13,** No. B-0012, Batoids indet., profile (11), occlusal (12), and basal (13) views, ×13. **14, 15,** No. B-0159, Batoids indet., lateral (14) and basal (15) views, ×19. **16,** No. B-0010, *Rhinobatos* sp., ×13. **17,** No. B-0124, *Paranomotodon* sp., lateral view, ×4. **18, 19,** No. B-0178, *Ptychotrygon triangularis* (Reuss), basal view (18), ×19, and posterior view (19), ×13. **20, 21,** No. B-0167, *P. triangularis,* (Reuss), occlusal (20) and anterior (21) views, ×19. **22,** No. B-0154, *Ischyrhiza* cf. *avonicola* Estes, oblique view of oral tooth, ×13.

Discussion—Ischyrhiza avonicola was first described from the Maastrichtian Lance Formation of Wyoming (Estes, 1964). It also is known from the lower Senonian of Belgium and the Turonian of South Dakota and Texas (Cappetta, 1973). Cappetta noted that Turonian specimens are significantly smaller than those from the Maastrichtian.

The Sclerorhynchidae comprise the Sawfishes, characterized by a long, swordlike rostrum lined with teeth and used to obtain food. Modern Sawfish are mainly found in tropical and subtropical coastal waters. However, a broad salinity tolerance is evident, and Sawfish commonly enter brackish as well as fresh water.

ISCHYRHIZA MIRA Liedy, 1856
Fig. 3/21

1856. *Ischyrhiza mira* Leidy, p. 221.
1964. *Ischyrhiza mira* Leidy: McNulty and Slaughter, p. 107, pl. 1, figs. 1-9.
1968. *Ischyrhiza mira* Leidy: Slaughter and Steiner, p. 235, fig. 1.
1975. *Ischyrhiza mira* Leidy: Cappetta and Case, p. 27, pl. 8, figs. 1-20.
1983. *Ischyrhiza mira* Leidy: Lauginiger and Hartstein, p. 14, fig. 5, pl. 4, figs. 48-51.

Description—The peduncle is relatively broad and slightly longer or subequal to the enamel cap. The base of the peduncle is broader than its apex. Ribbing present on peduncle. The enamel cap is well developed, not overhanging at juncture with peduncle.

Discussion—The rostral teeth of *Ischyrhiza mira* are substantially larger than those of *I. avonicola.* This report of *I. mira* represents a modest range extension of the species. Slaughter and Steiner (1967) and Cappetta and Case (1975) report the range of *Ischyrhiza mira* in the broad sense as late Turonian to late Maastrichtian (see also McNulty and Slaughter, 1964). Slaughter and Steiner recognize two subspecies: *Ischyrhiza mira schneideri* (late Turonian through Coniacian) and *Ischyrhiza mira mira* (early Campanian through late Maastrichtian). The Atarque specimens probably represent *I. mira schneideri.*

Genus PTYCHOTRYGON Jaekel, 1894
PTYCHOTRYGON TRIANGULARIS (Reuss, 1845) Fig. 5/3-8, 18-21

1845. *Ptychotrygon triangularis* Reuss, pl. II, figs. 14-19.
1894. *Ptychotrygon triangularis* (Reuss): Jaekel, p. 133, fig. 27.
1973. *Ptychotrygon triangularis* (Reuss): Cappetta and Case, p. 511, pl. 2, figs. 1-6.

Description—Small but massively constructed teeth, longer than wide, with heavily rugose crown. **The** roots are low, composed of two elongated, triangular lobes separated by a deep groove. Each lobe is perforated by a large, circular foramen. A large foramen is present medially in the groove, which is keyhole shaped in profile. The crown is roughly arcuate in profile and is separated from the roots by a depression along the rounded dorsal surface of the root. Medially, an anterior visor projects forward and terminates in a blunt edge. The posterior surface of the crown is shallowly concave in profile and is bordered by a ridge which may be papillate. The crown is ornamented by strong longitudinal ribs separated by prominent troughs. The suite of specimens displays a variety of wear states.

Discussion—Ptychotrygon triangularis is quite distinctive in appearance. It is abundantly represented in the Joyita Hills collections.

P. triangularis is known from the Turonian of Czechoslovakia and South Dakota (Cappetta, 1973; Evetts, 1979). Cappetta and Case (1975) reported *P. triangularis* from the Campanian of New Jersey; however, Cappetta (1975) redescribed the New Jersey material as a new species, *Ptychotrygon vermiculata.* Thus, it appears that *P. triangularis* has a stratigraphic range limited to the Turonian.

The Joyita Hills sample differs in some respects from the South Dakota material: the Joyita Hills specimens have more arcuate crowns, are not as triangular, and show minor differences in ornamentation. More detailed comparisons of larger samples may allow for finer stratigraphic differentiation of the Turonian.

Of additional interest is the fact that specimens of the Joyita Hills sample vary in color from almost black to yellowish-brown. The significance of these color variations is unclear, but may relate to the thermal history of the area.

"BATOIDS INDET."
?RHOMBODUS sp.
Fig. 5/11-15

Description—Small teeth with distinctive flat, rhomboidal crowns with weakly developed submedial keel and sloping facets. The margin of the crown is thick, rounded, and smooth in lateral view. The crown overhangs a well-developed and divided root.

Discussion—These specimens resemble *Rhombodus,* but it is impossible to refer them unequivocally to that genus without detailed histological studies.

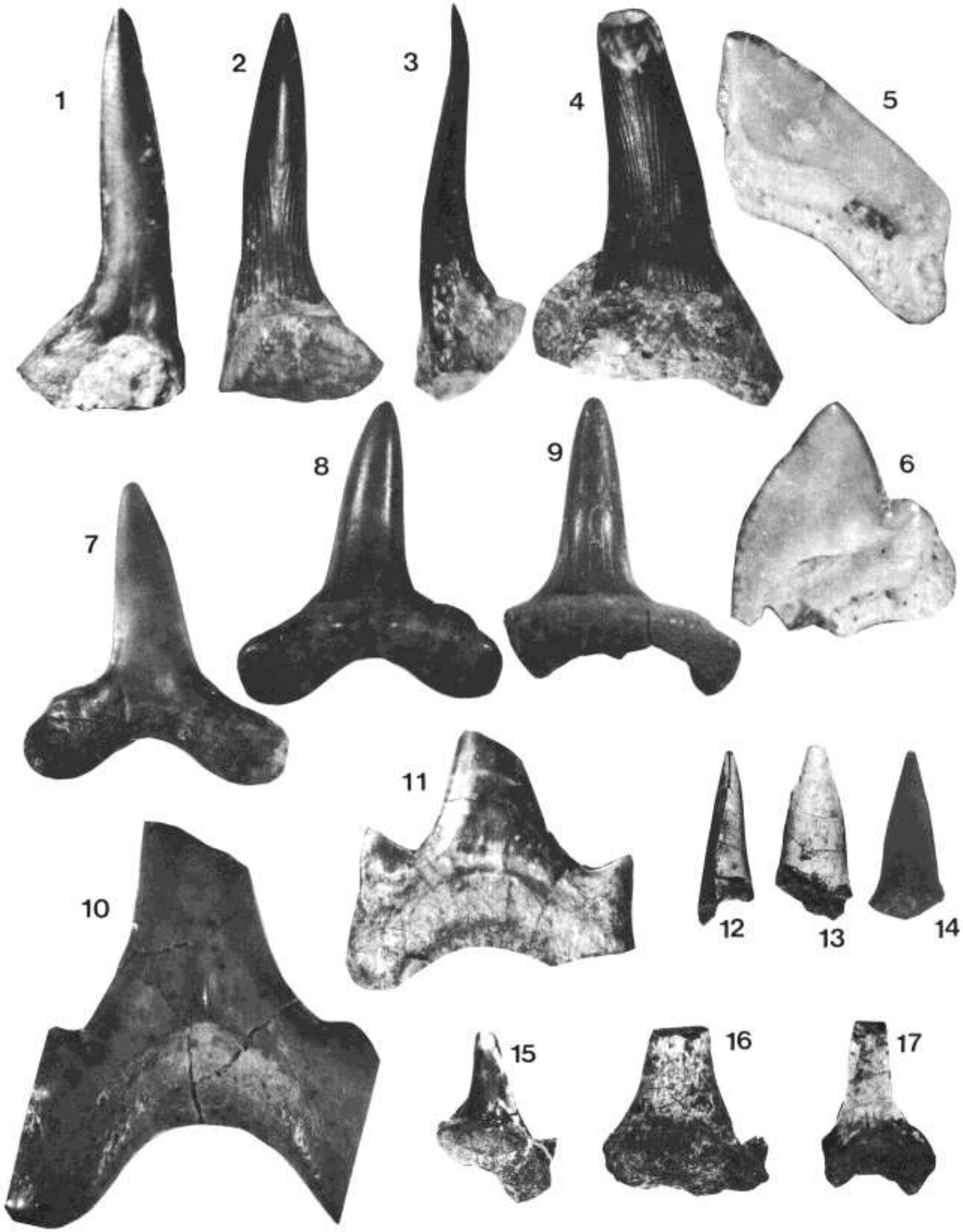

FIGURE 6—*Scapanorhynchus, Squalicorax, Anomotodon*, and *Cretolamna* from the Turonian at the Sevilleta Grant. **1–3,** No. B-0111, *Scapanorhynchus raphiodon* (Agassiz), outer (1), inner (2), and profile (3) views, ×5.6. **4,** No. B-0177, *S. raphiodon*, inner view, ×6.5. **5,** No. B-0201, *Squalicorax falcatus* (Agassiz), ×8. **6,** No. B-0015, *S. falcatus*, ×8. **7, 8,** No. B-0166, *Anomotodon* sp.; outer (7) and inner (8) views, ×3. **9,** No. B-0156, *Anomotodon* sp., ×4. **10,** No. B-0200, *Cretolamna appendiculata* (Agassiz), view, ×4. **11,** No. B-0161, *C. appendiculata* (Agassiz), ×4. **12, 13,** No. B-0128, *C. appendiculata* (Agassiz), ×1.2. **14,** No. B-0125, *C. appendiculata* (Agassiz), ×1.2. **15,** No. B-0114, *C. appendiculata* (Agassiz), ×1.5. **16,** No. B-0155, *C. appendiculata* (Agassiz), ×1.5. **17,** No. B-0118, *C. appendiculata* (Agassiz), ×1.2.

Conclusions

Sélachians frequently comprise a significant portion of Cretaceous marine, brackish, and even freshwater faunas of the Western Interior of North America. Only sporadic studies have been conducted on these faunas for the Western Interior as a whole, and even less is known of selachian faunas of New Mexico. The La Joya locality provides an opportunity to study a relatively large and diverse sample adequately placed in a stratigraphic context by invertebrate data. In this report, 19 selachian taxa are documented from the Atarque Sandstone Member of the Tres Hermanos, and most of them represent first occurrences from New Mexico. This fauna compares well with that reported by Cappetta (1973) and Evetts (1979) from the Turonian portion of the Carlile Shale of South Dakota, as well as with roughly equivalent-age faunas from the upper Midwest (Witzke, 1981). The fauna reported by Edwards (1976) from the Codell Sandstone in Colorado is too small for comparison. Given more complete samples through the Cretaceous strati-graphic record, selachian faunas, especially the smaller teeth, offer the possibility of better correlations.

Ecologically, selachians have been relatively conservative animals through time; fossil selachian assemblages probably can provide good paleoenvironmental data. Analogs for many Cretaceous selachian taxa are present today. Based upon the data available, the fauna reported here probably occupied a nearshore environment. The presence of relatively unabraded turtle, crocodile, and dinosaur bone fragments indicates a nearby landmass and riverine or estuarine habitats. The selachian fauna is relatively unbiased in that bottom-dwelling and actively swimming forms are well represented.

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"The science of Fossils, or Paleontology, is that upon which the geological history of the earth mainly rests. Without it, geology would be but a fragmentary science, a science of the structure of the earth only. By the aid of fossils, the succession of rocks, their distribution and relations are determined. They are the key which unlocks the most difficult problems of stratification. Upon them the seeker after the economic substances of the earth must mainly depend. Until the paleontologist has deciphered the records, the geologist can only grope blindly. The study of fossils,then, needs no apology from the economist. As a pure science, paleontology is inextricably united with the science of biology, the science of living things; as an applied science, it is equally intimately related to the structure and history of the earth. In the tracing of the rocks' strata, physical characters are often deceptive and unreliable; paleontological characters are decisive and incontrovertible."

(From S. W. Williston, 1898,
Geological Survey of Kansas, Vol.
IV, Paleontology, Pt. I, Upper
Cretaceous, p. *9—Preface.)*

Shark vertebrae from the Upper Cretaceous Pierre Shale, northeastern New Mexico

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Abstract

UNM F-133 is the natural mold of an incomplete vertebral column of a shark from the Upper Cretaceous Pierre Shale near Wagon Mound, Mora County, New Mexico. The vertebral centra are similar to lamnoid centra, and the preservation of this specimen suggests that other rare and fragile fossils of sharks may be present in the Pierre Shale in northeastern New Mexico.

Introduction

Very little is known about the Late Cretaceous sharks of northeastern New Mexico. The few occurrences of chondrichthyan fossils hitherto reported from this part of the state are: (1) Teeth of *"Isurus" sp., Lamna texana,* and *Ptychodus whippleyi* from limestone (Niobrara Formation?) on the banks of the Canadian River southeast of Springer (Newberry, 1876: 33, 141); (2) teeth of *Ptychodus whippleyi* from the Pierre Shale(?) near Las Vegas (Williston, 1900: 243); (3) chimaeroid egg capsules from the Trinidad Sandstone near Raton (holotype of *Chimaerotheca newmexicana* Brown, 1946) and Crow Creek Canyon near Koehler (Brown, 1946: 263-264, pl. 38, figs. 3, 5, 6); (4) abundant shark teeth in the upper part of the Carlile Shale in southeastern Colfax County (Wood et al., 1953), and (5) teeth of *Ptychodus* cf. *whippleyi* from the Carlile Shale at Storrie Lake north of Las Vegas (Griggs and Northrop, 1956: 136). We add to this sparse record the natural mold of part of a shark vertebral column from the Pierre Shale near Wagon Mound. UNM refers to the Department of Geology, University of New Mexico, Albuquerque.

We thank M. Starr for drawing Figure 3, and J. Zidek and B. Kues for comments on an earlier draft of this paper.

Provenance

The mold of the shark vertebrae (UNM F-133) was collected from the Pierre Shale about 13 mi northeast of Wagon Mound, in T. 22 N., R. 22 E., Mora County, New Mexico (Fig. 1). There is no record of who collected the specimen or when it was donated to the UNM collection.

The Pierre Shale in northeastern New Mexico is as much as 1,640 ft thick and consists mostly of dark gray marine shale. In the Raton Basin, north of Mora County, the Pierre ranges from early Campanian to earliest Maastrichtian (Cobban, 1976). The Pierre Shale at the locality belongs to the lower part of the formation (Bachman and Dane, 1962) and thus is probably of Campanian age.

FIGURE 1—Map of Mora County, New Mexico, showing the distribution of the Niobrara Formation and Pierre Shale (from New Mexico Highway Geologic Map) and the location from which the mold of the shark vertebrae (UNM F-133) was collected.

Description

UNM F-133 is a natural mold of 24 vertebral centra (here numbered 1-24 for convenience) in light olive-gray calcareous shale (Fig. 2A). A silicon-rubber cast was made from this mold (Figs. 2B, 3). All 24 centra are biconvex and circular in antero-posterior view. Two antero-posteriorly elongated pits visible in centra 2-8, 11, 12, and 17-24 (Fig. 3) are for the base of the dorsal arch. In centra 14 and 15 two circular, more widely spaced pits are for the base of the ventral arch (Fig. 3). Thus, on the cast, the dorsal surfaces of centra 2-8, 11, and 12 are exposed, the lateral edges of centra 17-24 are exposed (their dorsal arch bases face to-

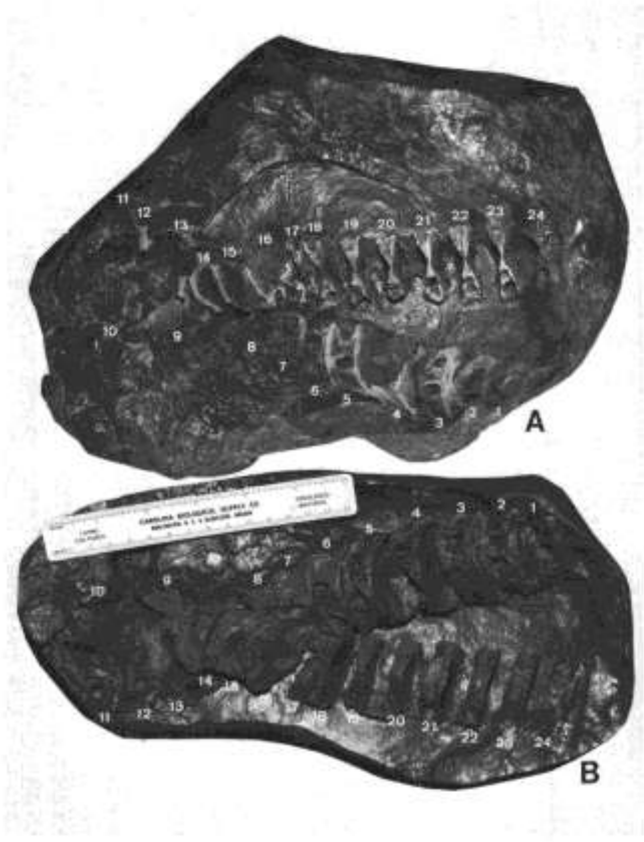

FIGURE 2—UNM F-133, natural mold of partial vertebral column of a shark (**A**) and silicon-ribber cast from the mold (**B**).

TABLE 1—Approximate measurements (in mm) taken with needle-point dial calipers of the maximum transverse diameter (**d**) and maximum antero-posterior length (**l**) of the vertebral centra of UNM F-133 (Fig. 2B).

Centrum number (Figs. 2, 3)	d	l
1	—	20
2	40	20
3	44	21
4	43	17
5	44	15
6	38	14
7	37	14
8	—	14
9	—	—
10	30	—
11	31	13
12	34	13
13	40	—
14	36	—
15	33	8
16	37	6
17	35	—
18	37	11
19	39	11
20	38	12
21	42	11
22	41	11
23	41	11
24	—	12

wards centra 1-7), and centra 9, 10, 13-16 are inclined so that the anterior or posterior articular surfaces are exposed. Centrum 1 is so poorly preserved that its orientation is not determinable.

The centra of UNM F-133 are aligned in two rows that cross each other at an acute angle. Approximate measurements of the centra indicate that there is a general decrease in centrum length from 1 through 24 and a less consistent decrease in centrum diameter from 2 through 7 and from 23 through 10 (Table 1). The orientation and size relationships of the centra suggest two possibilities:

(1) UNM F-133 represents parts of the vertebral columns of two sharks. The anterior end of one partial column (centra 1-8 and 11-13) is at centrum 1, and its posterior end is at centrum 11. The anterior end of the other column (centra 9, 10, and 14-24) is at centrum 24, and its posterior end is at centrum 10.

(2) UNM F-133 represents part of the vertebral column of one shark. One possibility is that the anterior end of this column is at centrum 1; this centrum is followed by centra 2-8, 13, 12, and 11. There then is a break in the column, and it has been twisted around to continue with centra 9 and 10 followed by 14-24. Another possibility is that centra 9 and 10 belong between centra 8 and 14, and that centrum 24 follows centrum 11. In that case, 16 and 15 (the shortest centra) are posteriormost. This last possibility would arrange the centra so that there is a nearly consistent decrease in diameter and length from the anterior

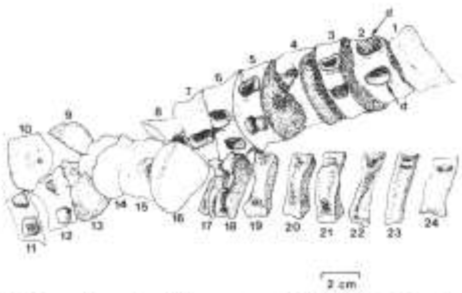

FIGURE 3—Drawing of rubber cast of UNM F-133: **d** = pits for dorsal-arch bases.

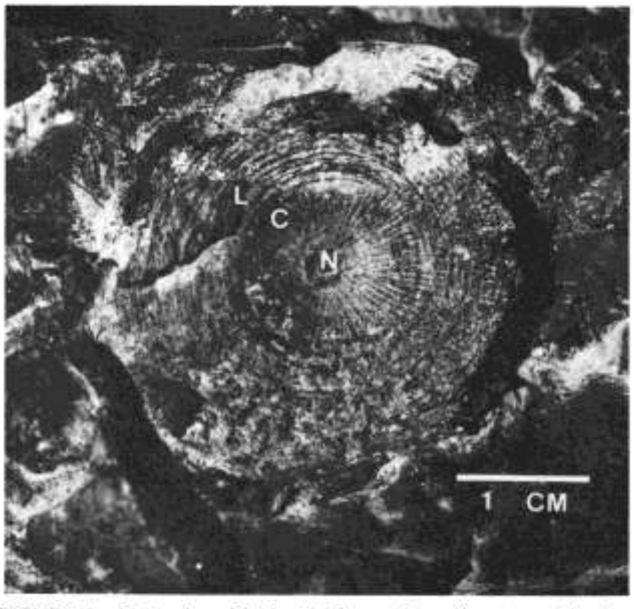

FIGURE 4—Natural mold of articular surface of centrum 10: **C** = primary double-cone calcification; **L** = concentric lamellae; **N** = notochord.

(centrum 1) to posterior (centrum 15) end of the preserved column, as in extant sharks. Because of this, and because of the close proximity and similarity of all the centra, we favor the idea that only one individual is represented.

Other than the dorsal and ventral pits, there is no surface detail preserved on the mold except on centrum 10, where the central articular surface is clearly divided into three concentrically arranged zones (Fig. 4). The small zone in the center probably represents the constricted notochord; the middle zone of radiating lamellae can be interpreted as the primary double-cone calcification; and the outer zone consists of concentric lamellae (Ridewood, 1921, figs. 2, 3).

Discussion

If UNM F-133 represents a single individual, the following observations are relevant. Upon death, the carcass, probably still intact or nearly intact, sank to the bottom; lacking a swim bladder, sharks have negative buoyancy. Post-mortem rigor resulted in craniad flexing of the posterior portions of the animal. Supportive muscle, integument, and other tissues must have been present before the shark was covered by sediment in order to account for the completeness and close proximity of the vertebral series. While exposed, but after post-mortem flexing, decay and/or scavenging took place, as indicated by the displacement of some vertebrae. Entombing sediments then sealed UNM F-133 from further depredation by scavengers or dissociation by currents.

The taxonomy of post-Paleozoic fossil sharks is based almost totally on teeth, so without dental remains it is impossible to precisely identify UNM F-133. Some workers (Hasse, 1879-1882; White, 1938; Applegate, 1967) have used vertebral structures to diagnose higher taxonomic groups of sharks, but Ridewood (1921) documented variation in vertebral structure within a single shark genus, and thus questioned the efficacy of this procedure. In addition, the vertebral characters used by the above workers are those seen in transverse sections through centra, or on radiographs, so comparable information cannot be obtained from UNM F-133. In having concentric lamellae around the primary double-cone calcification, UNM F-133 is "asterospondylous" (Hasse, 1879-1882), and it is similar to lamnoid centra (Hasse, 1879-1882, pls. 29, 34, 37; Goodrich, 1930, fig. 25; Applegate, 1967, pl. 2-4, fig. 1). Comparison with published illustrations of Cretaceous shark centra also does not aid in the precise identification of UNM F-133. For example, the centra of *Corax?* (Williston, 1900, pl. 24) lack radiating lamellae, and those of *Synechodus* (Woodward, 1889, pl. 12, fig. 6) are relatively longer and have ribbing on their lateral aspects, unlike UNM F-133.

Perhaps the significance of UNM F-133 is that it represents a rare case of preservation of a fragile structure. It thereby suggests that further collecting in the Pierre Shale in northeastern New Mexico might produce more informative remains of sharks.

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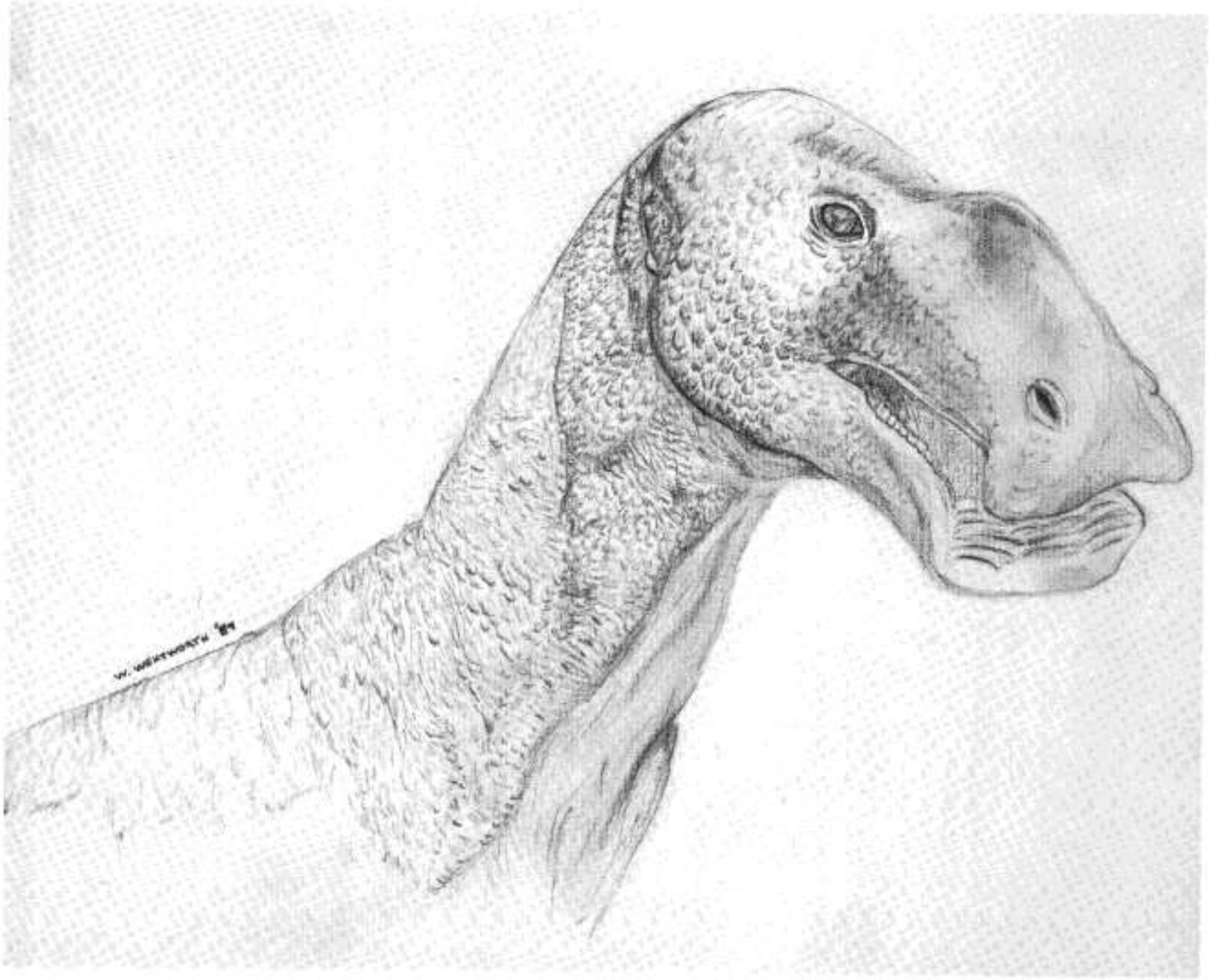

Kritosaurus, reconstruction by Wayne Wentworth, 1984

Depositional environments and paleontology of Lewis Shale to lower Kirtland Shale sequence (Upper Cretaceous), Bisti area, northwestern New Mexico

by Peter J. Hutchinson[1] and Barry S. Kues[2]

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Abstract

The Lewis Shale through lower Kirtland Shale sequence in the southwestern San Juan Basin represents offshore marine to deltaic and flood-plain sediments deposited during the last regression of the Midcontinent sea out of New Mexico in the Campanian and early Maastrichtian. Study of this sequence in a restricted area of about 110 km^2 near the former site of the Bisti Trading Post has yielded detailed information on the depositional environments and distribution of biota within units of this sequence. The Lewis Shale here consists primarily of prodelta shales containing abundant late Campanian palynomorphs and planktonic foraminifers, overlain gradationally by delta-front shoal and distal mouth-bar sandstones. The Pictured Cliffs Sandstone includes primarily delta-front distributary mouth bar, distributary channel, and beachfront sandstone facies with a thin lignite lens that probably represents part of a levee deposit. Fossils are limited to *Ophiomorpha* and sparse, poorly preserved marine invertebrate fragments.

The Fruitland Formation consists of lower, middle, and upper delta-plain sediments. Paludal and brackish conditions dominated the lower delta plain, whereas the middle and upper delta-plain environments, consisting of a complex and laterally variable association of vertically accreted carbonaceous shales, distributary sandstones, and several coal beds, were better drained and more heavily vegetated. The upper delta-plain fades is characterized by the absence of significant coal beds and is capped by a delta-top-sheet sandstone unit representing a dispersal center where channels and sediment diverged from a major stream or river, to be distributed over the lower parts of the delta plain. We regard this as a logical position for the Fruitland–Kirtland boundary within the study area. The lower shale member of the Kirtland, characterized by lighter, less carbonaceous shales, lack of significant coal beds, and smaller, less numerous channel sandstones, is interpreted as a flood-plain facies. The entire delta-plain sequence of the Fruitland could have been deposited (in the Bisti area) in as little as 200,000 years, based on sedimentation rates in modern deltas.

The distribution of fossils through the Fruitland and lower Kirtland, based on nearly 300 localities within the study area, shows several trends. Most of the biomass and the highest diversity within the Fruitland were present in the middle and especially in the upper delta-plain fades. The lower delta plain, influenced more by periodic influx of marine waters, contains a much less diverse biota dominated by turtles. The Kirtland flood-plain facies has, with a few exceptions, approximately the same biota as the Fruitland delta plain, but the abundance of all groups is much less, suggesting that the biota on the flood plain encompassed a much lower and more dispersed biomass than was present on the Fruitland middle and upper delta plain.

A microvertebrate assemblage was sampled using screen-washing techniques at one locality in the middle delta-plain facies—relatively low in the Fruitland. This assemblage consists mainly of fish teeth (especially *Amia, Paralbula, Myledaphus,* and *Lepisosteus)* and a variety of crocodilian teeth, with few dinosaurs, lizards, and mammals. Several types of small chondrichthyans are also present. The assemblage reflects accurately the major constituents of a local, slightly brackish-stream-dwelling community, with only slight introduction of elements from terrestrial communities. Vertebrate remains present in the assemblage that have not previously been reported from the Fruitland include the ray *Ptychotrygon,* the phyllodontid teleost cf. *Pseudoegertonia,* the dinosaur *Thescelosaurus?,* and small fragments of reptilian (possibly dinosaur) egg shells.

Introduction

The Bisti area is part of an extensive system of badlands developed in predominantly non-marine Upper Cretaceous and Paleocene units along the western and southern margins of the San Juan Basin of northwestern New Mexico. Erosion of the relatively flat Holocene surface by the Chaco River and its tributaries during the past few thousand years has produced this highly dissected topography, exposing the Cliff House, Lewis, Pictured Cliffs, Fruitland, and Kirtland Formations of Late Cretaceous age, and the Ojo Alamo and Nacimiento Formations of Paleocene age. Along the exposed surfaces of these units are found diverse assemblages of fossil plants, invertebrates, and vertebrates, and several coal beds of the Fruitland Formation. Early studies of these badlands concentrated mainly on the systematic paleontology, stratigraphy, and coal geology of the units. As the broad outlines of the geology and paleontology of this sequence were established, attention turned in recent years to more detailed studies in three general areas: (1) the biostratigraphy of the sequence, especially with respect to the position of the Cretaceous—Paleocene boundary; (2) interpretation of the depositional environments represented, in order to better understand not only the paleoecology of the fossil assemblages, but also the processes affecting the formation and distribution of coal in the Fruitland Formation; and (3) determination of the recent geomorphic processes responsible for the creation of the badland topography.

In this paper, a small area of badlands near the site of the former Bisti Trading Post in southwestern part of the San Juan Basin is considered in detail. The Bisti badlands have become a focus of interest for a variety of reasons: faunas and floras of the Fruitland and Kirtland Formations are particularly abundant here; large reserves of coal amenable to economical recovery by strip mining are present at and near the surface; and the badland topography is especially well developed, to the extent that some believe it should be preserved in its natural state as a wilderness area. Our purpose here is to comprehensively summarize previous geological and paleontological studies of the area, present in detail our interpretation of the depositional environments represented by the Upper Cretaceous Lewis Shale through lower Kirtland Shale sequence, and discuss an unusual brackish-water microvertebrate fauna from the lower part of the Fruitland.

Acknowledgments—We thank Spencer Lucas, University of New Mexico, and Donald Wolberg and Adrian Hunt, New Mexico Bureau of Mines and Mineral Resources, for reviewing the manuscript and offering helpful suggestions on its improvement. J. Keith Rigby, Jr. provided the facilities and helped with the screen-washing of the bulk sediment sample. The Museum of Southwestern Biology, University of New Mexico, kindly allowed examination of several modern fish and reptilian specimens that aided our understanding of related forms in the Fruitland and Kirtland Formations. Some of the paleontological information presented here is based on specimens collected under contracts with the U.S. Bureau of Land Management and Western Coal Company (now Sunbelt Mining Company). Sunbelt was helpful also in providing information about Fruitland-Kirtland geology and coal distribution within their leased areas near Bisti. We are also grateful to Richard Estes, San Diego State University, for examining and identifying several specimens of lower vertebrates from the Fruitland and Kirtland over the past few years. Finally, we are indebted to Kenneth Kietzke for taking the Scanning Electron Microscope photographs.

Location and stratigraphic setting

The study area encompasses sections 1-18, T. 23 N., R. 13 W., sections 6, 7, and 18, T. 23 N., R. 12 W., sections 19-36, T. 24 N., R. 13 W., and sections 19, 30, and 31, T. 24 N., R. 12 W.—a total of 42 sections in southern San Juan County, New Mexico, approximately 50 km south of Farmington (Fig. 1). It lies immediately east of the Navajo Reservation boundary along NM-371, and includes a large area of badlands of the Fruitland and Kirtland Formations between Hunter and Alamo Washes, together with chiefly Quaternary deposits along De-na-zin Wash, which forms the approximate southern boundary of the area. Most of the study area is east of the former site of the Bisti Trading Post (NW 1/4 NW 1/4 sec. 32, T. 24 N., R. 13 W.), and includes the entire 16.3 km^2 Bisti Wilderness area as designated by the U.S. Congress in October 1984. The study area is within the Bisti Trading Post, Alamo Mesa West, Tanner Lake, and The Pillar 3 NE 7 1/2 min U.S. Geological Survey topographic quadrangles. Geologic maps of the first two quadrangles have been completed by O'Sullivan et al. (1979) and Scott et al. (1979), respectively; a geologic map of the entire area was presented by Hutchinson (1981a) and is included here as Fig. 2. Most of this land is under federal jurisdiction, but a few sections are State of New Mexico or Indian land.

Within the study area are exposures of the upper part of the Cliff House Sandstone, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and part of the lower shale member of the Kirtland Shale (Fig. 2). The Cliff House Sandstone, a transgressive shoreline unit, is restricted to small isolated outcrops in the extreme southwestern part of the area and will not be discussed in this paper. The Lewis and Pictured Cliffs Formations crop out only in the southernmost tier of sections (secs. 14-18, T. 23 N., R. 13 W.), along the north side of De-na-zin Wash. The Fruitland and Kirtland Formations are much more widely exposed as an area of highly dissected, nearly barren badlands

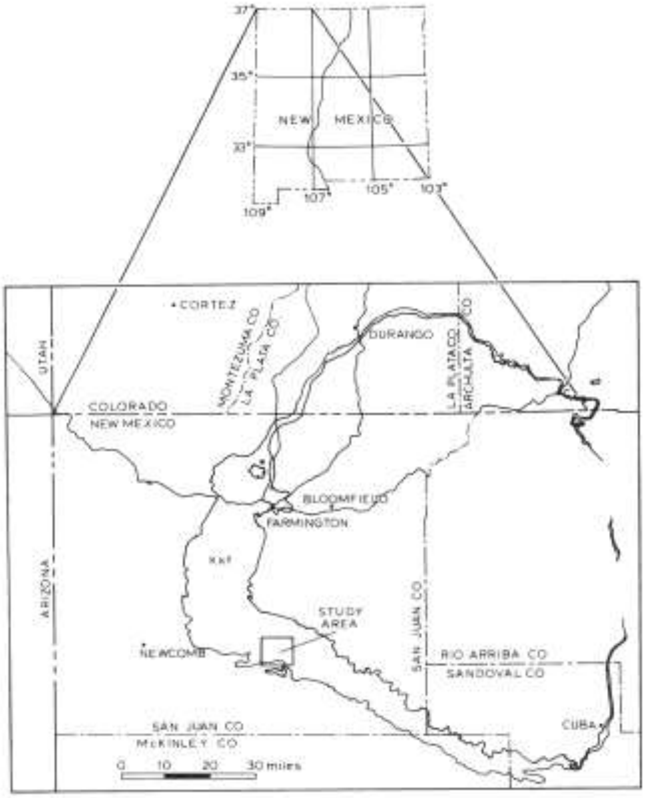


FIGURE 1—Location of study area in northwestern New Mexico showing Fruitland–Kirtland outcrop belt (Kkf).

containing numerous arroyos, hills, ridges, and grotesquely eroded, sandstone-capped pinnacles. About one third of the study area is covered by Quaternary deposits, chiefly unconsolidated silt, sand, and gravel, and local eolian dune sands, especially in the northwest, southeast, and south-central parts of the area. In this paper we do not discuss the Quaternary units, but studies of Quaternary stratigraphy and geomorphic processes near Hunter Wash and in other areas (Smith, 1983; Schultz, 1983; Wells et al., 1983) have demonstrated that the majority of the Bisti and neighboring badlands formed after regional development of an eolian unit dated at 2800 to 5600 years B. P.

The Upper Cretaceous sequence in the study area records, at its base (Cliff House and lower part of the Lewis), part of the last significant marine transgression in the western San Juan Basin, followed by a series of offshore to deltaic facies deposited as the Midcontinent sea made its final regression northeastward out of New Mexico. The age of this sequence ranges from late Campanian to possibly early Maastrichtian. The Cliff House Sandstone at Chaco Canyon, just to the south of the study area, contains abundant specimens of the ammonoid *Baculites per-plexus*, indicative of an early (but not earliest) late Campanian age (Siemers and King, 1974), about 75 m.y.B.P. (Obradovich and Cobban, 1975). Although no ammonoids identifiable to the species level have been found in the Lewis or Pictured Cliffs in the vicinity of the Bisti area, Fassett and Hinds (1971) reported *Didymoceras nebrascense* (middle late Campanian, about 72-73 m.y.B.P.) from the Pictured Cliffs at a level about 150 m above the Huerfanito Bentonite Bed in the Lewis, and noted that the age of the Pictured Cliffs decreases from the southwestern to northeastern part of the San Juan Basin. Using their assumption of 300,000 yrs for each 30 m rise of the Pictured Cliffs, and noting that the Pictured Cliffs is 45 m above the Huerfanito Bentonite near the study area, it would appear that the Pictured Cliffs exposures there are about 73-74 m.y. old.

Clemens (1973) believed that the mammals of the Hunter Wash local fauna (upper Fruitland—lower Kirtland) were slightly younger than the *D. nebrascense* range zone, or late Campanian, and later (Clemens et al., 1979) tentatively referred this fauna to the Edmontonian land-mammal "age." L. S. Russell (1975) also considered the Fruitland—Kirtland fauna to be no older than Edmontonian (late Campanian—early Maastrichtian), although Judithian and Lancian elements are also present. Lucas (1981) showed the Fruitland and lower Kirtland Formations as being mainly of Judithian age, but ranging up into the early Edmontonian, indicating a primarily Campanian but possibly also an early Maastrichtian age. Brookins (1982) and Brookins and Rigby (1983) reported K—Ar dates from the lower part of the Kirtland within the study area that averaged about 71-72 m.y.B.P., very close to the Campanian—Maastrichtian boundary as determined by Obradovich and Cobban (1975). It should be noted here that the most recently published date for the Campanian—Maastrichtian boundary (Palmer, 1983) is 74.5 m. *y.B.* P. Because documentation for that date has not yet been published, and the uncertainty is 4 m.y., we have used Obradovich and Cobban's (1975) date consistently in this discussion for the Upper Cretaceous sequence in the San Juan Basin.

The above-mentioned ages, based on biostratigraphic and radiometric data, contrast with the results of magnetostratigraphic studies by Butler et al. (1977) and Lindsay et al. (1981), which place the entire Fruitland—Kirtland sequence within the late Maastrichtian. Problems with the magnetostratigraphic data and interpretations have been summarized most recently by Lucas and Schoch (1982) and Lucas et al. (in press). Considering all of the evidence available at present, only the uppermost part (Naashoibito Member) of the Kirtland (not exposed within the study area) appears to be of Lancian or middle to late Maastrichtian age (Lehman, 1981; Lucas and Schoch, 1982; Lucas et al., in press).

A generalized stratigraphic section of the units exposed within the study area is given in Fig. 3.

Previous studies

Our knowledge of the geology and paleontology of the Lewis to Kirtland sequence in the San Juan Basin has developed mainly within the past 75 years, although the first fossils were reported by Cope in 1885. Reference to earlier studies of the Lewis and Pictured Cliffs Formations is made in the sections of this paper devoted to those units; this discussion is limited to previous studies of the Fruitland and Kirtland Formations. Early work (1900-1925) was principally directed toward determining the stratigraphy and distribution of these and other Upper Cretaceous to lower Tertiary units in the San Juan Basin, sampling the fossils, and evaluating the coal beds of the Fruitland for their economic potential. Relatively little was published about the Fruitland and Kirtland during the following 35 years, but beginning in the 1960's, and continuing to the present, studies of these formations have intensified. Early work was summarized by Knowlton (1916) and Gilmore (1916), and a wealth of additional information about later studies, much of it dealing with the Bisti to Ojo Alamo area, was presented by Clemens (1973). Major papers on the Fruitland and Kirtland have recently been listed by Wolberg and Kottlowski (1980) and Lucas (1981). The following discussion is limited to previous studies of these formations in the Bisti area.

Paleontology and geology

The first reconnaissance of the Bisti area of which there is a record was made by W. J. Sinclair and Walter Granger for the American Museum of Natural History in the summers of 1912 and 1913. Primarily engaged in studying Paleocene strata near Ojo Alamo, Sinclair

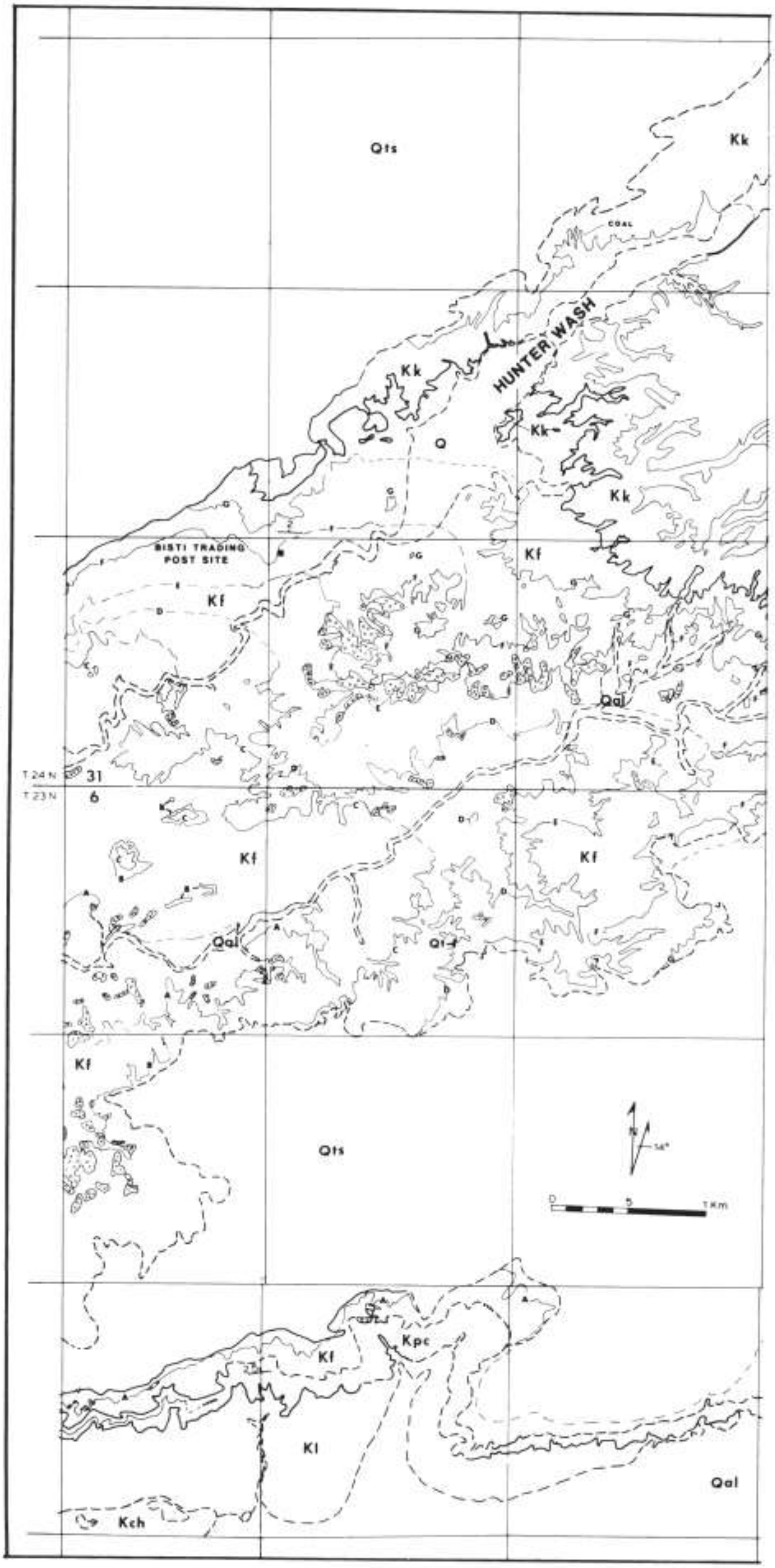
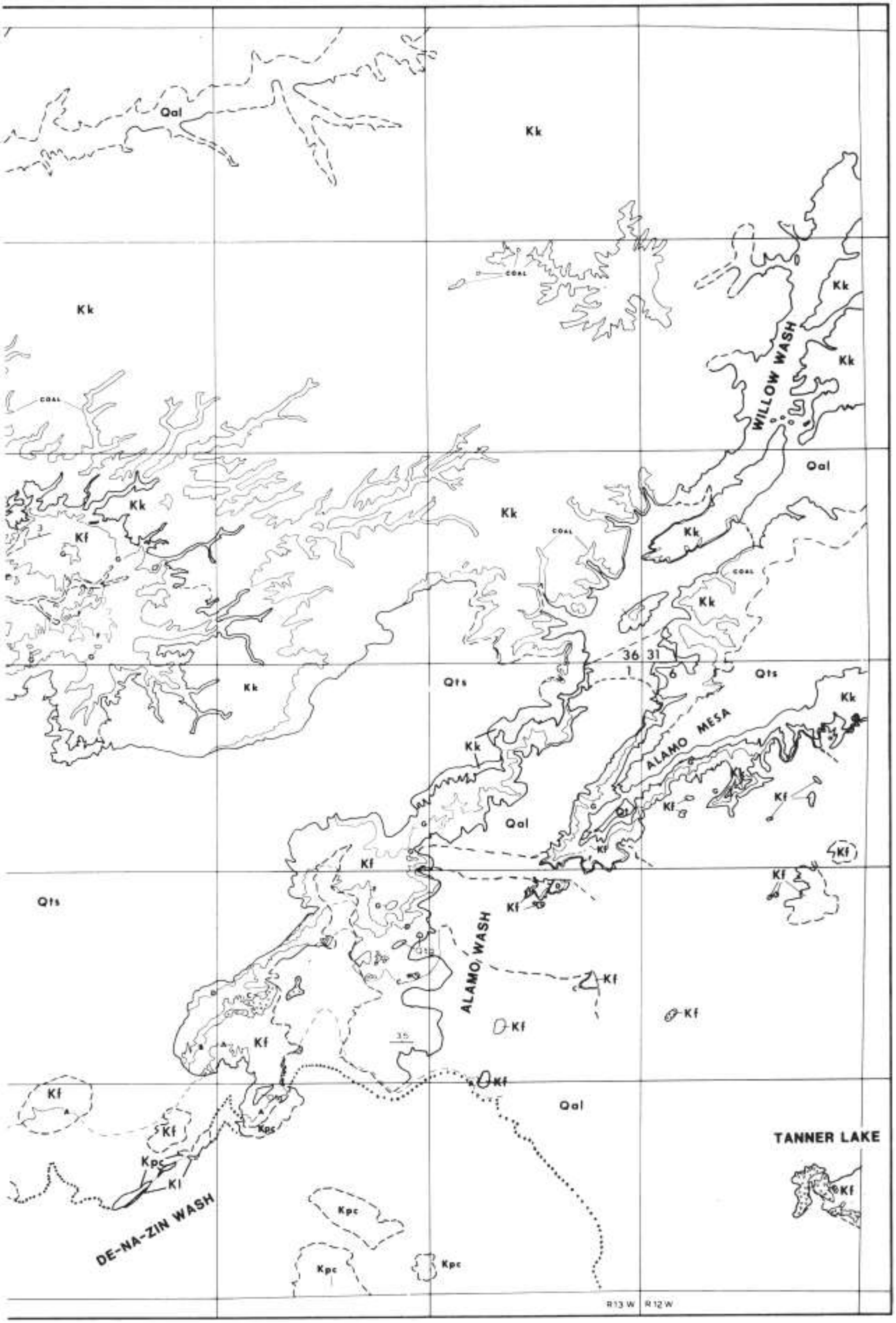


FIGURE 2—Geologic map of study area showing formations exposed, coal beds (A–G) identified in text, and major geographic features.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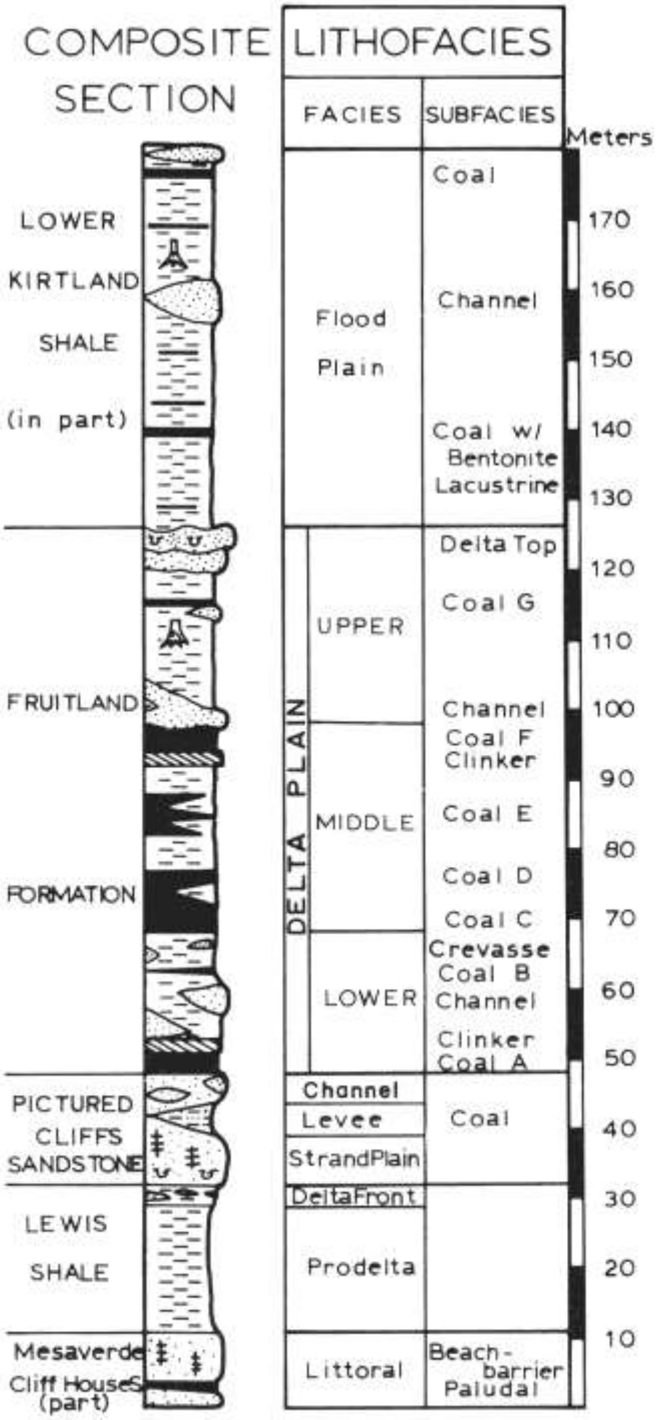

FIGURE 3—Composite stratigraphic section within study area based on 29 stratigraphic sections reported by Hutchinson (1981a). Thickness of coal beds has been exaggerated and complexity of facies relationships simplified and generalized for clarity.

and Granger (1914: 302) mentioned "A trip down Ojo Alamo Arroyo to a point some eight miles below the store," which probably took them into the eastern part of the study area. They noted the presence of turtle and other reptilian remains, but apparently made no collections.

In 1915 a U.S. Geological Survey party led by C. M. Bauer mapped in detail the Upper Cretaceous to lower Tertiary units in an area extending roughly from Ojo Alamo north and westward into the Navajo Reservation to the San Juan River. In addition to defining the Fruitland and Kirtland Formations and recognizing the presence of the Pictured Cliffs Sandstone beneath the Fruitland, Bauer (1916, pl. 65, section E—E') recorded a stratigraphic section measured south of Hunter Wash together with 11 fossil localities (Bauer, 1916, numbers 71-81 on pl. 64) in the area near "Hunter's Store" (about 1.6 km northeast of the Bisti Trading Post site, fide Clemens, 1973: 161). Bauer recognized the brackish to fresh-water depositional environment of the Fruitland and Kirtland, including the presence of fluvial channels, and suggested that the Kirtland was possibly deltaic or lagoonal. He also noted the gradational nature of the transition between the two formations.

Fossils collected by Bauer's party from the Bisti area included a single species of unionid bivalve, *Unio* (now *Proparreysia) holmesianus,* from the Fruitland (Stanton, 1916), and 18 plant species, including the type specimens of six new species, all from the Kirtland: *Quercus baueri, Ficus baueri, Heteranthera cretacea, Carpites baueri, Ficus praelatifolia,* and *Pterospermites neomexicanus* (Knowlton, 1916). Some vertebrates were also recovered and described by Gilmore (1916); they included a carnosaur tooth, crocodilian teeth, and gar scales from the Fruitland, and hadrosaur phalanges and cervical vertebrae, carnosaur and crocodilian teeth (including *Brachychampsa),* gar scales, ray teeth, and the type specimen of a new species of turtle, *Neurankylus baueri (= N. eximius,* according to Gaffney, 1972), from the Kirtland.

Reeside and others returned for further work in the San Juan Basin in 1916, 1917, 1920, and 1921. Although there is no indication that additional paleontological collections were made from the Bisti area during that time, near Ojo Alamo Reeside discovered the first Late Cretaceous sauropod remains known from North America (Gilmore, 1922). Reeside (1924) presented a detailed map and a summary of the stratigraphy and paleontology of the western San Juan Basin, but added little new information about the depositional environments or paleontology of the units within the study area.

In the summer of 1921 the great fossil collector C. H. Sternberg visited the Fruitland—Kirtland badlands and later described his field experiences in the southwestern San Juan Basin (Sternberg, 1932). Sternberg stopped at several places in the Ojo Alamo and Kimbeto areas, collecting turtles, dinosaurs, and a crocodilian skull that he sold to the Swedish paleontologist Carl Wiman, who eventually described them in the early 1930's (see also Mateer, 1976, 1981, for additional information about these collections). While camping at the Ojo Alamo Trading Post, Sternberg met Reeside, who told him of "the rich field for turtles at Hunter's Store" (Sternberg, 1932: 207). Making his way into the Bisti area, Sternberg quickly discovered "many beautiful turtles" in the Fruitland and Kirtland Formations, and remarked that "in one locality, not over one hundred by two hundred feet, I secured at least fifteen different individuals" (Sternberg, 1932: 219).

In 1929 a Smithsonian Institution party led by C. W. Gilmore explored the Fruitland and Kirtland badlands, beginning near Kimbeto, moving on to the Ojo Alamo area, and then to Hunter's Store. Gilmore (1930: 20) reported that an "articulated tail of a large hadrosaurian dinosaur; portions of the skull of a horned dinosaur of the *Chasmosaurus* type, new to the fauna and probably a new species; articulated limb and foot bones of a small ceratopsian reptile; and no less than 20 turtles, many of them complete shells and some of large size, are a few of the outstanding acquisitions."

Gilmore (1935) described in more detail the specimens obtained during 1929, along with some turtles purchased from Sternberg, collected in "1923" (1921?), and other specimens, in a paper that summarized the reptilian faunas of the Fruitland known to that time. Specimens from within the study area included a right squamosal of *Pentaceratops sternbergii,* seven species of turtles, including the new species *Boremys grandis, Thescelus hemispherica, Baena ornata,* and *Basilemys nobilis,* together with gar scales, and the teeth of My*ledaphus* and a squatinid shark. The first two turtle species have since been shown to be synonyms of *Boremys pulchra* and *Thescelus insiliens,* respectively (Gaffney, 1972).

Gilmore (1930: 21-22) concluded his report on the 1929 fieldwork by stating that "[as] a collecting field for fossil vertebrates, the San Juan Basin area, taken as a whole, is disappointing. Extensive areas of well dissected bad lands with surfaces practically free from vegetation and debris, an abundance of 'float' or surface indications of fossils, are ideal conditions that give every promise of yielding rich returns. It was found, however, that in the greater number of instances, the clues followed led only to a single or at most two or three bones of a skeleton. It was readily apparent that individual skeletons had been widely scattered before interment, and that isolated or partially articulated specimens are rarities."

C. H. Sternberg (1932: 222) recorded a different impression of the Bisti and neighboring badlands: "I therefore record with pleasure, that though I had gone into a virgin field which one of the greatest living collectors of reptiles had thought was not worth the trouble of exploring, I secured, during the time I spent there, fourteen thousand pounds of Cretaceous vertebrates . . ." If this is a reference to Gilmore's delay in collecting from the San Juan Basin Cretaceous, it is somewhat unfair. One reason why Gilmore's 1929 expedition did not find more complete vertebrate remains was undoubtedly the fact that Sternberg had collected the best of the exposed material in the early 1920's. Earlier expeditions had either been brief, or, as in the case of the U.S. Geological Survey fieldwork in 1915 and later, were directed more toward determining the geology and stratigraphy of the area than making comprehensive collections of fossils.

As stated above, most of the fossils collected by Sternberg for Wiman came from east of the study area, but Mateer (1981) noted that several turtles in these collections were found in T. 24 N., R. 13 W.—probably within the study area. Wiman (1930) reported *Pentaceratops?* from "Alamo Wash, 3 miles above Hunter's Store" in the Fruitland Formation. This locality is vague, as nowhere is Alamo Wash within three miles of the site of Hunter's Store, but it probably was within the study area.

Little paleontological or geological work was done in the Bisti area during the 1940's and 1950's. In 1962 through 1967 field parties from the University of Kansas Museum of Natural History made numerous collections from the Bisti Trading Post area, including the first Fruitland-Kirtland mammals and a *Pentaceratops* skull from the SW^1/4 sec. 34, T. 24 N., R. 13 W. (Rowe et al., 1981). Clemens (1973) described this University of Kansas work in some detail. At about the same time the U.S. Geological Survey began a basin-wide study of the Fruitland and Kirtland Formations to provide a basis for classifying public lands in outstanding coal withdrawals. Fassett and Hinds (1971) provided a thorough summary of these formations and established a general interpretation of their depositional environments. Although the Bisti area was not specifically discussed in detail, these authors did present a preliminary list of mammals collected from the Hunter Wash area, as identified by Clemens.

In the 1970's the University of Arizona, under the direction of Everett Lindsay, began a program in the southwestern San Juan Basin designed both to study the vertebrate paleontology of the Upper Cretaceous-lower Tertiary sequence and to collect samples for paleomagnetic analysis (see Butler et al., 1977; Lindsay et al., 1981). Several vertebrate localities were discovered within the Bisti area, primarily along the south side of Alamo Mesa, including a ceratopsian skull a few meters east of the study area in NW 1/4 ^{N}W 1/4 sec. 5, T. 23 N., R. 12 W. A screen-washed microvertebrate collection from sec. 34, T. 24 N., R. 13 W. was turned over to Armstrong-Ziegler, who incorporated the information derived from it into her studies of Fruitland-Kirtland microvertebrates (Armstrong-Ziegler, 1978, 1980). Powell (1973), in a paper devoted mainly to the Ojo Alamo Sandstone, presented a list of the constituents of the Hunter Wash local fauna, including many of the vertebrate taxa known from the Bisti area at that time.

In recent years, paleontological surveys done both for the Bureau of Land Management and for coal companies that anticipated mining in the Bisti and neighboring areas (e.g. Froehlich and Kues, 1977; Kues et al., 1977; LeMone, 1979) have substantially increased the amount of information available on Fruitland-Kirtland fossil localities and biota, and led to increased paleontological activity and public interest in the Bisti area. Kues et al. (1977) reported nearly 300 fossil localities in the Fruitland and Kirtland within the study area, and recorded several taxa that had not previously been known from these formations. LeMone (1979) intensively surveyed 2^1/2 sections of state land in the study area and reported 1458 fossil occurrences, including 619 from which collections were made. Wolberg and LeMone (1980) presented a progress report of this survey and a preliminary faunal list. Study of the substantial collections obtained during these paleontological surveys, as well as collections made subsequently by a number of institutions, is continuing.

Recent papers on the geology of the Fruitland and Kirtland in the study area include preliminary maps of the Bisti Trading Post and Alamo Mesa West quadrangles (O'Sullivan et al., 1979; Scott et al., 1979), and discussion of stratigraphy and depositional environments (Erpenbeck, 1979; Erpenbeck and Flores, 1979; Hunt et al., 1981; Hutchinson, 1981a, b; Flores and Erpenbeck, 1982). Recent work on the paleontology of the Bisti area has added significantly to knowledge of the Fruitland and Kirtland biota there. Armstrong-Ziegler (1980) described the reptiles and amphibians from the microvertebrate locality mentioned above; Lucas (1981) made the first real attempt to summarize Fruitland—Kirtland paleoecology, based in part on observations in the Bisti area; Robison et al. (1982) described the most diverse plant assemblage yet reported from these formations, at a location in the lower Kirtland in the SW 1/4 NE 1/4 sec. 32, T. 24 N., R. 13 W.; and Kues (1983) reported on some unusual invertebrates from the microvertebrate locality discussed later in this paper.

Coal geology

Part of the early interest in the geology of the Bisti area and of the Fruitland Formation in the San Juan Basin generally stemmed from the occurrence of coal in this formation. Shaler (1907) provided the first relatively detailed regional map of the western San Juan Basin, including the Bisti area. He assigned some of what is now called the Fruitland and Kirtland Formations to the "Laramie Formation," following the custom of the previous 30 years. Some of the Bisti outcrops, however, appeared as "undifferentiated Tertiary" on Shaler's map, and no fossils were reported from the area. Shaler did note that some coal in the uppermost "Mesaverde Formation" near the southwestern part of the study area was mined for use at the Tiz Natzin Trading Post, and briefly described the coal in several "Laramie" outcrops south of Coal Creek (De-na-zin Wash), probably just to the south of the study area.

Bauer (1916) gave stratigraphic sections for several places in the western San Juan Basin, including the Hunter Wash area. These sections show several coal beds limited to the Fruitland. Later, Bauer and Reeside (1921) published a detailed summary of the distribution, stratigraphy, and chemical and physical characteristics of the coal in the San Juan Basin. They accurately described the coal stratigraphy of the Hunter Wash area and reported six major and two minor lenses of coal. They concluded at the time that Fruitland coal, because of its relatively low heating value and lack of transportation facilities, could not compete economically with coal then being mined in other parts of New Mexico and Colorado.

Interest in Fruitland coal increased during the 1950's, and in 1961 the BLM issued two federal coal leases to the predecessor of Sunbelt Mining Company (BLM, 1982a). These leases cover a substantial percentage of the study area. Studies to define more accurately the extent and thickness of Fruitland coal were undertaken by the coal companies, private consultants, and the U.S. Geological Survey. Beaumont (1971) comprehensively discussed the occurrence of coal in the Fruitland across the entire San Juan Basin, and Shomaker (1971) provided data on the coal resources in what he called the "Bisti—Fruitland" area, an area about five times the size of the present study area that extends from the Navajo Reservation southeastward past Kimbeto. He estimated the total coal reserves of the Bisti—Fruitland area at 1870 million tons beneath 75 m or less of overburden, and characterized the coal as being "subbituminous, high-ash, low-sulfur coal" (p. 110). Recently, the New Mexico Energy and Minerals Department (1982) reported that the total surface-mineable coal reserves for the Bisti area (presumably equivalent to Shomaker's Bisti—Fruitland area) were 1421 million tons. Shomaker (1971) also discussed the coal reserves in T. 23 N., R. 13 W. and T. 24 N., R. 13 W., which include the major part of the present study area, and he estimated the strippable coal reserves at 276 million tons. Ninety million tons of recoverable coal were reported to lie within the Bisti Wilderness study area (BLM, 1982b: 2-2), which represents about 15% of the study area.

Additional information about Fruitland coal was published by Fassett and Hinds (1971), who provided a depositional model for coal formation and presented coal sections based on outcrops and numerous subsurface cores for more than 300 locations throughout the San Juan Basin. Only two of these sections (242, 268), however, were within the study area. Brief descriptions of the coal deposits in the Bisti area were given by Beaumont et al. (1976) and Fassett et al. (1977); the areal extent of individual coal beds is portrayed on the geologic maps of O'Sullivan et al. (1979), Scott et al. (1979), and Hutchinson (1981a).

Western Coal Company (now Sunbelt Mining Company), following an intensive drilling program on its leased lands near Bisti, designated eight coal seams and estimated the total reserves in their leased area at a little more than 80 million tons (Hutchinson, 1981a). The company numbered the coal seams 1 through 8 from the stratigraphically lowest to highest; Hutchinson (1981a) designated these seams A through G, with Coal F being equivalent to Western Coal Seam 8, and Coal G being a minor seam not designated by Western Coal. Hutchinson's (1981a) nomenclature for the coal beds is followed in this paper.

At present, provisions for exploiting the coal resources within the study area are uncertain. In 1979 the BLM established the Bisti Wilderness study area; subsequently, it recommended the area as a federal wilderness area (BLM, 1982b), which it became in 1984. The BLM also entered into a procedure by which lands under lease for coal mining in the wilderness study area were traded by the lease holder for lands of equal economic value elsewhere in the southern San Juan Basin. Two of Sunbelt Mining Company's currently or recently active strip-mine operations exist on state land within the study area: the De-na-zin mine (N^1/2 sec. 16, T. 23 N., R. 13 W.) and the Gateway mine (sec. 32, T. 24 N., R. 13 W.). In addition, about 14 sections, primarily in the north and northeast parts of the study area, are Preference Right Lease Application areas (PRLA's). These are existing lease applications dating from the early 1970's, which had been deferred pending development of federal coal-program regulations. At present, the BLM (1982c) intends to issue leases for all or most of these PRLA areas in the near future. Some of these areas would be destined for underground rather than strip mining (BLM, 1981, map 1-3 following p. 150).

With the coming of coal mining to the state lands of the Bisti area and the prospect of additional mining on federal lands within and adjacent to the study area, the questions of the effects of mining on the recovery of paleontological information and the coordination of mining activities and paleontological studies has assumed importance. Various views on this subject have been expressed in paleontological survey reports for the Bisti area cited above, in papers by Wolberg and Kottlowski (1980), Kues (1982), and Wolberg (1982), and in a wide variety of BLM and other reports.

Lewis Shale

The Lewis Shale, first defined by Cross et al. (1899) at exposures near Durango, Colorado, was recognized shortly thereafter around the southern end of the San Juan Basin (e.g., Shaler, 1907) and in the Bisti area (Bauer, 1916; Reeside, 1924). The Lewis generally consists of dark-gray, fine-grained clastic sediments deposited offshore in relatively deep water during the last short transgression and beginning of the final regression of the Midcontinent epeiric sea northeastward out of the San Juan Basin. The paleontology and depositional environments of the Lewis have been studied primarily on the eastern side of the basin (e.g., Anderson, 1960; Cobban et al., 1974; Mannhard, 1976).

The Lewis Shale is poorly exposed in the study area except where it is stabilized by the overlying Pictured Cliffs Sandstone, and varies in thickness from approximately 21 to 34 m eastward across secs. 16, 17, and 18, T. 23 N., R. 13 W. Throughout most of this thickness the formation consists of relatively uniform, dark-brown to black, finely laminated claystones and shales, with local, minor, dark-brown, lenticular, very fine- to medium-grained quartzose-sandstone beds. Deposition of this lithofacies occurred in an open marine environment in quiet conditions, chiefly as a result of the slow settling of small suspended particles derived from low-lying coastal swamp and delta-plain environments not far to the southwest. The Lewis Shale is much thinner in the study area than elsewhere to the north and northeast, and wedges out between the shoreline facies of the transgressive Cliff House Sandstone and regressive Pictured Cliffs Sandstone about 19 km to the west, near the Newcomb Trading Post (Beaumont, 1971: 25; Fassett and Hinds, 1971: 9). Thus, the Lewis in the Bisti area marks a very transitory offshore environment associated with maximum southwestward transgression of the Lewis sea. Longstanding existence of fluvial and deltaic conditions to the southwest, perhaps associated with lagoonal environments as represented by the upper Menefee Formation (Beaumont et al., 1976: 28), and the relatively nearshore position of Lewis deposition suggest that most of the thickness of the Lewis in the study area is best interpreted as a prodelta facies. Throughout much of the San Juan Basin, in areas that were farther offshore and far removed from the direct effects of coastal deltaic sedimentation, the Lewis represents a neritic shelf environment. Coleman (1981: 33) noted that in many instances shelf deposits can be distinguished from prodelta facies "only when the associated subaqueous delta complex is known either in a vertical or plan view sequence."

Large fossils are sparse in the Lewis and are generally restricted to local sandstone lenses. Bauer (1916) reported a small collection of bivalves and ammonoids from his locality 82, north of the mouth of Dena-zin Wash and just west of the study area. This locality was examined and a small fauna including *Ophiomorpha*, *Granocardium* sp., *Inoceramus?* sp., and *Placenticeras?* sp. was collected. These and similar local sandstone lenses within the normal mudstone and shale lithologies of the Lewis probably represent offshore shoals.

Although the mudstones and shales of the Lewis in the study area contain sparse invertebrates, microfossils are abundant. Analysis of samples collected from four levels through the Lewis revealed ostracodes, a moderately diverse assemblage of foraminifers (Table 1), and a diverse palynomorph flora (listed in Hutchinson, 1981a). The foraminiferal assemblages observed consist almost entirely of planktonic forms, many of which are also known from the late Campanian of the Gulf Coast. Many of the spore and

TABLE 1—Microfauna of the Lewis Shale, Bisti area. Locality Li, about 5 m above base of Lewis, SW 1/4 sec. 18, T. 23 N., R. 13 W.; Locality L2, about 18 m above base of Lewis, same coordinates as L1; Locality L3, top of prodelta facies, 5 m below base of Pictured Cliffs Sandstone, SW 1/4 ^{N}W 1/4 sec. 17, T. 23 N., R. 13 W:; Locality L4, delta-front facies of Lewis, about 3 m below base of Pictured Cliffs Sandstone, same coordinates as L1 and L2.

Group	L1	L2	L3	L4
Foraminifera				
Alabamina cf. *australis*		x		
Anomalinoides cf. melon is A. cf.				
pinguis		x	x	
A. sp. ("large aperture") *Bolivina*		x		
aff. *incrassata Dentalina*			x	
megapolitana Globigerinelloides				
aff.				
prairehillensis				
Globotruncana cf. *calcarata*				
G. cf. *rosetta* aff. *Globotruncana*		x		
Heterohelix pulchra			x	
H. cf. *pulchra*				
Lenticulina cf. *muensteri* cf.			x	
Operculina Foraminifera				
gen. et sp. indet. Ostracoda				
gen. et sp. indet. Sponge		x		
spicules		x	x	

countered the oxygen-poor peat bed while working their way through the overlying sediment, and turned away from it.

Within the study area, the distributary-channel facies is overlain at the top of the Pictured Cliffs by very fine-grained sandstones and siltstones representing tidal inlet, tidal channel, and back-barrier environments developed prior to, and seaward of, the interdistributary swamps that produced much of the deposition of the lower part of the Fruitland Formation.

Fruitland and lower Kirtland Formations

Depositional environments

The Fruitland Formation was early recognized as a unit gradationally overlying the Pictured Cliffs, and as having been deposited in brackish to fresh-water environments landward of the shoreline sands of the Pictured Cliffs (Bauer, 1916; Reeside, 1924). Fassett and Hinds (1971) stated that the Fruitland represents coastal swamp, river, flood-plain, and lake deposits. Erpenbeck and Flores (1979) and Flores and Erpenbeck (1982) interpreted Fruitland environments in detail as consisting of fluvial-channel and crevasse-splay sandstones, overbank and levee siltstones and shales, and coals and carbonaceous shales derived from swamps. Our studies of the Fruitland in the Bisti area have in general confirmed the observations and interpretations of the above-mentioned workers. We present here a summary of the depositional environments of the Fruitland and lower Kirtland Formations within the study area and information on the nature and distribution of fossils within these formations.

The base of the Fruitland is placed arbitrarily at the bottom of the lowest major coal bed (e.g., Bauer, 1916) or at the top of the first massive sandstone below the lowest coal (Fassett and Hinds, 1971). In the study area, this coal (Coal A) is generally divided into two beds by a medial carbonaceous shale, ranges from 1.5 to 6.0 m in thickness, and is the most widely distributed of the six major coal beds in the Fruitland. Coal A marks the establishment of the first areally large interdistributary swamp in Fruitland time. Flooding of distributaries built deposits of mud and silt laterally just above sea level along the prograding distal margin of the delta plain, producing a poorly drained, fresh- to brackish-water environment conducive to the growth of a luxuriant flora. The relatively great thickness of this lowest Fruitland coal bed suggests a period of stability in the position of the shoreline (Fassett and Hinds, 1971) and in the positions of major distributaries, allowing organic matter to accumulate autochthonously at a faster rate than that of fine-grained sediment influx. Although this swamp must have been close to the shoreline, marine influence was probably relatively slight, though periodic storms and wind-driven tidal surges would have introduced some seawater directly across these low areas and caused the temporary spread of saline waters up the distributaries, creating fluctuating brackish conditions. Aside from plant debris, the only fossils observed in the sediments of this paludal environment were indeterminate scraps of bone.

Above Coal A is a complex association of carbonaceous shales, channel sandstones, and a thin coal bed. These units were grouped collectively into an estuarine facies by Hutchinson (1981a) because of evidence for temporary increased influence of marine waters in some of the environments preserved in this part of the Fruitland section. Coal A is overlain by 3 to 12 m of finely laminated, dark-brown to dark-gray, carbonaceous shales deposited as overbank and interdistributary-bay sediments. Six to 12 m above the base of these shales is a thin, vertically split, rather poorly developed coal lens (Coal B), indicating the presence of marshes or swamps around the landward margins of, and locally within, the interdistributary bay. Interspersed above, below, and in places laterally gradational with this coal are channel deposits consisting primarily of trough crossbedded, fine- to coarse-grained quartzose sandstones. These channels, which increase in extent up-section, represent a complex pattern of distributaries and associated crevasses from which fine suspended sediments were spread into adjacent areas during flood stages, as in modern deltas (Coleman, 1981).

Development of crevasse splays in the lower Fruitland is indicated by a distinctive sequence of sediments representing the breaching of a channel and the deflection of some sediments through the opening. Unstructured, very fine-grained sandstones appear above interdistributary muds, and are overlain by a fine- to medium-grained, plane-bedded sandstone that represents the increasing through flow of water into the developing crevasse channel. This deposit is in turn covered by large tabular sets of trough crossbedded, medium- to coarse-grained sandstones of the fully developed channel.

As noted above, the carbonaceous shales in this part of the Fruitland were deposited in the low-lying areas between major distributaries. These areas were poorly drained and probably contained substantial but seasonally variable amounts of standing fresh water that encouraged the growth of marsh and swamp vegetation, especially around their less inundated margins. Possibly because of greater incursions of marine waters into the interdistributary bays, the development of the vegetation that produced Coal B was not as extensive as that which formed Coal A. More pervasive encroachment of saline waters into the Bisti area during this time is suggested by the presence of the marginal-marine trace fossil *Ophiomorpha* in a distributary sandstone just below the stratigraphic level of Coal B in the NW 1/4 sec. 8, T. 23 N., R. 13 W. Transitory minor transgressions across interdistributary bays were probably caused by local abandonment of a distributary channel supplying sediment to the area, accompanied by slight subsidence of the low-lying sediments. Coleman (1981) noted similar processes in the Mississippi delta. Influx of marine waters up tidal and distributary channels and mixing with fresh river water would have created a variably brackish environment.

The degree of penetration of marine water inland across the Fruitland delta plain would have had a significant effect on the organisms living in aqueous environments. Most marine and fresh-water organisms cannot tolerate brackish conditions for long, and the number of organisms adapted to a permanent existence in brackish waters is relatively small (Emery et al., 1957). In modern estuaries, the greatest percentage of brackish organisms are salinity-tolerant species derived from marine environments (Emery et al., 1957, fig. 18), and it would be reasonable to expect this a priori to be true of organisms inhabiting Fruitland distributaries as well.

How far inland brackish environments extended during deposition of the Fruitland is difficult to estimate. Flow of salt water up modern delta channels is regulated by numerous processes, including tidal range, variations in river discharge, and sedimentary processes at the delta front. In some modern rivers brackish conditions may exist more than 30 km inland from their mouths (Emery et al., 1957: 699). Nelson (1970) showed that for the Po River delta, salt water is able to penetrate only slightly past the distributary-mouth bar under normal conditions, but during times of low river discharge and high tides "salt water penetrates far upstream" (p. 152).

Within the Fruitland, evidence of brackish environments must come chiefly from the identification of organisms that might reasonably have lived in brackish water, based on the ecological preferences of related organisms living today. Although much more documentation of Fruitland faunas is needed, especially of microvertebrates and aquatic invertebrates, several workers have reported the occurrence of brackish faunas relatively high above the base of the Fruitland. Armstrong-Ziegler (1980) interpreted two microvertebrate assemblages from the upper 15 m of the Fruitland as indicating an estuarine regime, based on significant percentages of euryhaline fish taxa. The exact stratigraphic position of these localities, relative to the base of the Fruitland, however, is not known. Hartman (1981) briefly noted that brackish environments, as indicated by non-marine molluscs, may be present as high as 35.6 m above the base of the Fruitland, and Kues (1983) described bryozoan and crab remains from a brackish unit about 30 m above the base of the formation. Collectively, these reports suggest that transitory brackish conditions extended intermittently several kilometers inland across the Fruitland delta plain through much of the time the Fruitland was being deposited. However, as the Fruitland delta prograded to the northeast, deposition of facies progressively farther from the shoreline, with diminishing marine influence, comprised the dominant trend of Fruitland sedimentation in the Bisti area.

Above Coal B the Fruitland consists of distributary-channel sandstones, vertically accreted shales, and four more major lenticular coal beds deposited on the middle part of the delta plain. Although the relationships between these facies are often complex, in general the pattern is one of meandering, shifting channels, deposition of fine-grained overbank sediments during flooding, and growth of extensive stands of swamp vegetation in the areas between the distributaries. Periods of relative stability of the distributaries allowed laterally widespread swamp vegetation to flourish and organic debris to build up, producing the relatively thick Coal C and Coal F deposits. Flores and Erpenbeck (1982) suggested reasonably that some of the thicker Fruitland coal lenses probably originated in the backswamps of abandoned distributary channels, an environment conducive to the stable accumulation of peat. During particularly severe floods or during a succession of abnormally wet years, large quantities of mud were spread into interdistributary areas, interrupting organic sedimentation and producing several thin coal lenses separated by shale, as is the case with Coal E.

In places, proximity to a major distributary resulted in peat accumulations—and probably much of the vegetation responsible for them—being eroded by the channel or inundated by rapid levee, overbank, and interdistributary-mud deposition. Locally, channel sandstones directly overlie, and have erosional contact with, coal beds; Coals C through F all show this relationship in places within the study area (Fig. 8). The widely varying shale thicknesses between major coal beds, a constant feature within the Fruitland, likewise in part reflect distance from distributary sediment sources. For example, Coals C and D are separated by 3-8 m of carbonaceous shale through the western part of the Bisti area, reflecting close proximity to a distributary, but locally to the east the shale wedges out, leaving the two coal beds vertically continuous. Facies variations and relationships, as well as local distribution of coal beds in the Bisti area, are shown well by Hutchinson (1981a, fig. 6) and Flores and Erpenbeck (1982, section A-A ').

Rapid aggradation of channels due to moderate to high sediment influx is common in the upper part of the Fruitland (Fig. 9). This, and the lack of significant coal beds above Coal F suggest that the upper-delta plain was well drained and a moderate slope existed, in contrast to the flat, more poorly drained configuration of the lower- and middle-delta plain. Approximately 5-20 m above Coal F is a continuous, widespread 0.5 m thick lignite bed (Coal G) that represents the highest significant accumulation of organic matter in the Fruitland Formation.

The Fruitland delta plain is capped by a sheet-sand deposit consisting of a lower, tan, fine- to medium-grained, massive- to medium-bedded quartzose sandstone, and an upper, dark-brown, ball-and-pillow structured, prolate, medium-grained to conglomeratic sandstone that locally has slumped down into the lower sandstone. Genetically, this sheet-sand deposit represents a dispersal center on the delta plain where channels and sediment diverged from the trunk stream. Moore (1966) called analogous deltaic sheet-like sandstones the "delta top," and noted that, except for the delta front, the delta top has the steepest gradient of the prograding delta wedge. In general, the bulk of

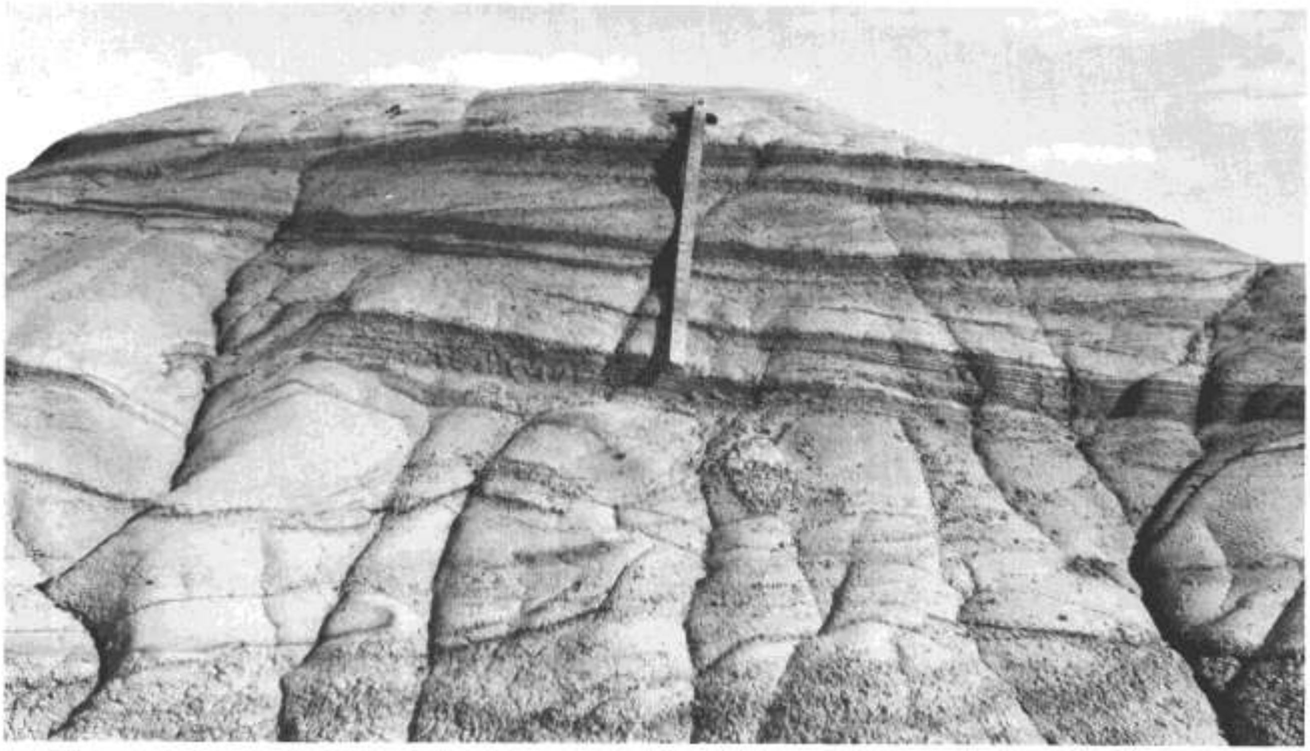

FIGURE 11—Channel sandstone in lower shale member of Kirtland Shale, flood-plain facies, top of measured section 28 of Hutchinson (1981a). Staff is 1.5 m long. View to northeast.

uninterrupted manner. Some shale units were probably deposited in low areas of the flood plain in transitory lakes whose margins fluctuated with seasonal and longer-term variations in river discharge, rainfall, amount of introduced suspended mud, and rate of local accumulation of plant detritus. In some areas, such as sec. 28, T. 24 N., R. 13 W., lacustrine deposition is indicated by a basal shale with a thin, lenticular, lignitic-coal bed, and a white, iron-stained, sharply based, gradationally topped bentonite bed immediately below the coal (Fig. 12). This bentonite bed, or similar ones in the lower Kirtland (in secs. 21 and 23, T. 24 N., R. 13 W.) yielded the radiometric dates reported by Brookins (1982) and Brookins and Rigby (1983). Most, if not all, of the lignitic-coal lenses in the lower Kirtland probably originated from the local concentrations of peat in low areas of the flood plain.

FIGURE 12—Lacustrine deposit of flood-plain facies, lower shale member of Kirtland Shale, near measured section 27 of Hutchinson (1981a). Note bentonite bed (b), overlain by a thin, lignitic coal seam. Staff is 1.5 m long. View to southwest.

Paleontology

Information about the biota of the Fruitland and Kirtland Formations is contained in taxonomic studies of a variety of groups, a few studies of the fauna and flora of single localities, up-to-date lists of identified taxa (e.g., Lucas, 1981; Tidwell et al., 1981; Robison et al., 1982), and good general overviews of the biota presented by Lucas (1981), Lucas and Mateer (1983), and Lucas et al. (in press). Study of the stratigraphic and ecological distribution of the biota, however, has only become possible with the recent addition of detailed information on the stratigraphy and depositional environments of these formations. In this section we discuss the biota of the Fruitland and lower part of the Kirtland in the study area within the context of the facies and stratigraphic relationships outlined previously in this paper. The paleontological data base used in our analysis is derived from nearly 300 localities within the study area, identified by Kues et al. (1977). During that study, all parts of the Bisti area were surveyed with approximately equal intensity, numerous collections were made, and the fossils obtained from each locality were identified to the extent allowed by the nature of the remains. Extensive screen-washing for microvertebrates and large-scale excavations of material were not done; however, the correlation of the larger and more conspicuous elements of the biota with specific stratigraphic intervals, as worked out by Hutchinson (1981a), makes possible the general summary of biotic distribution presented below. With additional collection and study of the Fruitland and Kirtland biota, both in the Bisti and neighboring areas, our preliminary conclusions will doubtless be refined, and the distribution of many individual genera and species determined.

For comparative purposes, we have divided the Fruitland and lower Kirtland into five stratigraphic intervals, each of which also represents a distinct depositional environment. These intervals are: 1) lower (paludal) delta plain—base of Fruitland to the shales immediately overlying Coal A; 2) lower (brackish) delta plain—shales overlying Coal A to Coal C; 3) middle delta plain—top of Coal C to top of Coal F; 4) upper delta plain—Coal F to top of delta-top sandstone (Fruitland–Kirtland boundary as used in this paper); 5) flood plain—lower shale member of Kirtland. It should be kept in mind that although each of these divisions predominantly represents a single, general depositional environment, transitory changes in the delta system may have brought other environments temporarily into the area. For example, brackish environments dominate the interval from Coal A to Coal C, but brackish faunas are also present in restricted beds in the interval from Coal C to Coal F.

The distribution of major faunal and floral groups, based on the number of localities each taxon occurs in within each of these intervals, is given in Table 2. As no identifiable fossils were found in the paludal horizon, it is not considered further. These figures show, in a general way, the relative abundance of each taxon compared to others within each of the divisions of the Fruitland to lower Kirtland sequence. We recognize that transportation of some remains from one part of the delta to another has probably affected to some extent the apparent distribution of some groups, so that their remains were ultimately deposited in a different facies than the one in which they died. However, this would affect small, easily transported organisms that lived in the distributaries (and small elements of large organisms) far more than the major skeletal elements of larger organisms. Because deposition over most of the delta and flood plain probably occurred relatively rapidly, creating the conditions for rapid burial, and because microvertebrates and other small organisms were not extensively collected or examined during this study, we believe that post-mortem transportation probably did not significantly affect the distribution of the groups considered in Table 2.

TABLE 2—Occurrence of Fruitland–lower Kirtland taxa in each interval through the sequence, expressed as percentages of the total localities within an interval that yielded remains of each taxon. The percentages add up to more than 100% in each column because several taxa were commonly found at a single locality. Interval I = Coal A to Coal C; II = Coal C to Coal F; III = Coal F to top of Fruitland; IV = lower shale member of Kirtland.

Group	Interval			
	I	II	III	IV
Dinosaur indet.	7	20	21	49
Ornithischia indet.	—	6	3	2
Hadrosauria	11	3	26	14
Kritosaurus	—	—	4	—
Parasaurolophus	—	1	—	—
Ceratopsia	—	3	10	6
Ankylosauria	—	—	1	1
Carnosauria	—	2	3	4
Coelurosauria	—	3	4	2
ALL DINOSAURS	19	40	73	79
Testudines indet.	59	60	46	45
Trionychidae	—	1	1	—
Basilemys	—	1	1	—
Adocus	—	1	—	—
Baena	—	—	—	1
ALL TURTLES	59	64	49	47
Crocodilia indet.	—	6	14	13
Goniopholis?	—	1	3	2
Brachychampsa	—	—	—	1
ALL CROCODILIANS	—	7	17	16
Squamata indet.	—	1	—	1
Lepisosteus	—	8	17	14
Amia	—	5	6	3
"Fish" (indet. holosteans & teleosteans)	—	2	6	3
Myledaphus	—	1	6	4
"shark" indet.	—	—	1	—
Mammalia (*Mesodma?*)	—	—	1	—
Bivalvia				
Unionidae and other bivalves	—	15	17	1
Teredina	—	5	1	—
Gastropoda	—	2	9	—
Plants				
Logs and stumps	11	19	23	10
Leaves indet.	4	3	3	2
Sabalites (palm)	—	8	3	—

Another possible source of bias is differential preservation, which might result in the remains of one taxon being preserved to a greater or lesser degree than the remains of another taxon that might originally have been equally abundant in a given environment at the same time. Sufficient information to evaluate the possible effects of differential preservation is not available at present. In addition, the small area of Fruitland–Kirtland exposures examined in this study probably does not include all of the microhabitats and biota present in the entire Fruitland–Kirtland outcrop. Finally, because large fossils are more easily seen in the field than small ones, there is probably some sampling bias towards larger fossils in this study.

In order to compare the relative abundance of a given taxon among the various fades or intervals where it occurs, it is necessary to adjust the abundance figures to take into account the areal extent of each facies. In other words, a large abundance of a taxon in one facies, relative to its abundance in another, may not be significant if the first facies is far more widely exposed. Thus, in Table 3, we have calculated the number of occurrences per section of exposure for the common taxa in each of the intervals of the Fruitland and lower Kirtland. From the data presented in Tables 2 and 3, several general statements may be made about the distribution of biota through these formations within the study area.

Most of the Fruitland fauna appears to have lived in the middle and upper parts of the delta plain; diversity and abundance are low in the lower (brackish) facies and are highest for almost all of the faunal elements in the upper delta plain. The paucity of fossils in the lower Fruitland has been remarked upon by many workers (e.g., Rowe et al., 1981). Turtles are by far the most dominant vertebrates in the brackish interval and occur in large numbers throughout the Fruitland delta. Of the dinosaurs, only hadrosaurs ranged to the shoreward margins of the lower delta plain, although they too were more common farther inland. Ankylosaurs had the most restricted distribution, being confined to the upper delta plain and Kirtland floodplain environments. The relative abundance of the various groups of dinosaurs is consistently the same in all of the facies: hadrosaurs predominate, with ceratopsians, coelurosaurs, carnosaurs, and ankylosaurs following the order of abundance. The relative abundance of dinosaur groups in the study area is the same as throughout the Fruitland, based on a census made by Lucas (1981: 361).

Comparison of the occurrences of various groups within the middle and upper delta plain (Table 2) indicates that remains of dinosaurs, crocodilians, and most fish groups occur more frequently in the upper than in the middle delta plain, whereas turtles are relatively less common in the upper delta plain. Plants, as indicated by log, stump, and leaf localities, and non-marine molluscs show relatively small differences, though palm trees *(Sabalites),* and the bivalve *Teredina* are more conspicuous in the middle-deltaplain facies. The organisms living on the middle and upper Fruitland delta plain were those that Lucas (1981) assigned to his *Parasaurolophus* community.

TABLE 3—Number of localities per section of exposure for common groups in intervals of the Fruitland–lower Kirtland sequence. Interval definitions are the same as in Table 2.

Group	Interval I	II	III	IV
Dinosaur indet.	0.9	5.5	5.0	3.9
Ornithischia indet.	—	1.5	0.7	0.2
Hadrosauria	1.3	1.2	7.0	1.1
Ceratopsia	—	0.9	2.3	0.5
Ankylosauria	—	—	0.3	0.1
Carnosauria	—	0.6	0.7	0.3
Coelurosauria	—	0.9	1.0	0.2
ALL DINOSAURS	2.2	10.8	17.0	6.3
ALL TURTLES	7.1	17.2	11.3	3.7
ALL CROCODILIANS	—	1.8	4.0	1.3
Lepisosteus	—	2.2	4.0	1.1
Amia	—	1.2	1.3	0.3
"Fish" (indet. holosteans and teleosteans)	—	0.6	1.3	0.3
Myledaphus	—	0.3	1.3	0.3
Unionidae and other bivalves	—	4.0	4.0	0.1
Teredina	—	1.2	0.3	—
Gastropoda	—	0.6	2.0	—
Logs and stumps	1.3	5.2	5.3	0.8
Leaves (including *Sabalites*)	0.4	3.1	1.3	0.2

Somewhat surprisingly, no occurrences of crocodilians or fish were reported for the lower (brackish) part of the delta plain, though it is known from microvertebrate studies (including the one discussed later in this paper) that crocodilians, *Lepisosteus, Amia,* and *Myledaphus* and other chondrichthyans were able to live successfully in brackish waters. Their apparent absence in the brackish facies is possibly partly due to sampling bias towards larger vertebrates (though *Amia* vertebrae, crocodilian scutes, and gar scales are fairly conspicuous and would have been observed if they were present), but we believe it also reflects their much greater abundance in the middle and upper parts of the delta plain. Most Fruitland brackish microvertebrate assemblages (e.g., Armstrong-Ziegler, 1980; Kues, 1983) are from restricted brackish units in the middle and upper parts of the delta plain, where salinity was probably significantly lower than near the shoreward margins of the delta.

Occurrences of non-marine molluscs in the Fruitland are likewise limited to the middle and upper parts of the delta plain in the study area. Several genera of unionids, the bivalve *Teredina,* and gastropods are moderately common in these facies and are locally present in high numbers. Stanton (1916) described more than two-dozen species of non-marine molluscs from the Fruitland, but only one was reported from the study area. About two-thirds of the species of bivalves and gastropods discussed by Stanton came from levels more than 30 m above the base of the formation, probably from interior delta-plain environments. However, several bivalves and a few gastropods were reported by Stanton from near the base of the Fruitland, possibly from units equivalent to our lower or brackish interval. The presence of some non-marine molluscs in brackish environments of the lower Fruitland is well established (Hartman, 1981), and a few marginal marine genera such as *Ostrea* have also been reported from the lower Fruitland (Stanton, 1916; Fassett and Hinds, 1971; Kues et al., 1977).

In contrast to their presence in brackish parts of the lower Fruitland elsewhere, no non-marine molluscs were observed in the lower (brackish) facies of the Fruitland within the study area. The reasons are unclear at present, but are probably related to subtle ecological features of the local, lower delta-plain environment that inhibited colonization. Unionids, for example, are primarily fresh-water molluscs, and the distribution of many modern species is strongly affected by such ecological factors as substrate characteristics and current velocity. Some species living in Fruitland delta-plain environments apparently tolerated brackish conditions, but the degree of tolerance undoubtedly varied from species to species. Occasional influx of highly saline waters, or significant periodic fluctuation of salinity across the lower delta plain may have created too rigorous an environment for most or all unionids to occupy successfully. Our impression is that Fruitland unionids preferred fluvial conditions and avoided both standing bodies of fresh water that were accumulating large amounts of plant debris and interdistributary bays that were subject to the influx of marine waters. Until further, more detailed studies of the distribution of brackish molluscs within the Fruitland are completed, the local absence of such molluscs in the lower Fruitland of the study area can only be attributed in general terms to the lack of a suitable mosaic of environmental conditions (including salinity, substrate, and other hydrologic factors) that would have allowed them to live there.

The relatively high concentration of the Fruitland fauna in the middle and upper parts of the delta plain was undoubtedly influenced significantly by the distribution, abundance, and types of plants growing there. Both leaf assemblages and localities with petrified logs and/or stumps are far more abundant in these more inland parts of the delta than toward its shoreward margins (Tables 2, 3). Although vegetation existed over all portions of the delta plain, as indicated by the presence of coal beds throughout the Fruitland, it seems clear that the density and general abundance of trees were much higher in the interior parts of the delta. The shoreward areas of the delta were poorly drained, subject to the influx of marine water, and characterized by relatively unstable sedimentation patterns—all factors that limit the successful growth of most kinds of trees (Odum, 1959). With these data, and by analogy with some modern deltaic environments, we visualize predominantly low-lying, salt-tolerant, non-woody plants and some trees across the lower part of the Fruitland delta, with diversity and abundance of coniferous and deciduous trees along with the smaller plants that constituted the undergrowth increasing away from the delta margins across the middle and upper parts of the delta. Robison et al. (1982) reached a similar conclusion based on their study of a lower Kirtland (upper Fruitland of our terminology) leaf florule in the Bisti area. The high biomass represented by the luxuriant vegetation developed in the interior delta plain supported relatively large numbers of herbivorous dinosaurs and other animals, and formed the trophic base of a complex and diverse food web outlined by Lucas (1981).

Dicotyledonous angiosperms are the predominant plants of the Fruitland and Kirtland (Tidwell et al., 1981) in terms of diversity and, locally, abundance. Eighty-four percent of the species in the florule described by Robison et al. (1982) consisted of dicotyledonous plants. According to Tidwell et al. (1981), many of the more common dicotyledonous trees lived in well-drained areas between swamps and in coastal-plain environments. Conifers, though not diverse in the Fruitland and Kirtland, were considered by these authors to have contributed significantly to the accumulation of peat in these formations, and, at least locally, comprised the dominant Fruitland vegetation. LeMone (1979) reported that gymnosperms comprised about 75% of the petrified wood found in the lands he surveyed within our study area. Preliminary analysis of the stump field at the "Fossil Forest," which occurs in the uppermost Fruitland (probably equivalent to the upper delta-plain facies in the Bisti area) about 10 km southeast of Bisti, revealed that most of the silicified tree remains were conifers (Wolberg and Rigby, 1981). Palm trees, monocotyledonous angiosperms, are represented mainly by isolated fronds and occasional fragments of roots in sandstone bodies in the middle and upper delta-plain facies within the study area, although Tidwell et al. (1981) reported many stem bases in growth position locally in the Fruitland in one area of the southeastern San Juan Basin, near Cuba, New Mexico. Undoubtedly, local variation in the composition of the forests that occupied the Fruitland delta plain occurred from place to place, but much more paleobotanical work, coupled with close attention to the occurrence of plant fossils within the various Fruitland facies, is required before detailed interpretation of these variations can be attempted.

The flood-plain facies of the lower part of the Kirtland contains a vertebrate fauna that, according to Lucas (1981: 363) is "inadequately sampled (and preserved)" and which represents a "taxonomically depauperate subset of the fauna of the Fruitland." Our studies indicate that most of the major faunal groups present in the middle and upper delta-plain intervals of the Fruitland are also present in the lower Kirtland, in roughly similar relative abundances (Tables 2, 3), lending some weight to the statement by Lucas et al. (in press) that the dinosaur faunas of the Fruitland and most of the Kirtland are "virtually identical." However, a major difference between the upper Fruitland and lower Kirtland is the low abundance of each major element of the Kirtland biota relative to its abundance in the upper Fruitland (Table 3). This is true of non-marine invertebrates and plants as well as vertebrates. Occurrences of non-marine molluscs are especially rare in the lower Kirtland of the study area, which accords with Stanton's (1916) observations for the entire Kirtland; only two of the 27 species he described from the Fruitland and Kirtland were present in the Kirtland. There is some evidence from Armstrong-Ziegler's (1978, 1980) work that the diversity of microvertebrates is relatively small in Fruitland-Kirtland environments that were farthest from the shoreline, and we suspect that if our study had been comprehensive down to the generic and specific level, it also would have shown a decrease in diversity along with a decrease in abundance from the upper Fruitland to lower Kirtland.

The biomass that existed on the lower Kirtland flood plain was significantly lower and more dispersed than that which existed on the middle and upper Fruitland delta plain, and, as suggested above, diversity was probably lower as well. Better drainage, fewer bodies of standing water, and more permanent channels that were topped by flood waters less frequently all contributed to conditions in which vegetation cover was less pronounced and produced far less peat accumulations than on the delta plain. Lucas (1981) suggested that the lower Kirtland fauna is in some respects transitional between the *Parasaurolophus* community of the Fruitland delta plain and the inland middle to late Maastrichtian *Alamosaurus* community known only from the Naashoibito Member of the Kirtland. Because the *Alamosaurus* community may be a few million years younger than the *Parasaurolophus* community, it would be of great interest to know more about the biota of the Kirtland between the top of the Fruitland Formation and the base of the Naashoibito Member. More study of these biota might allow several questions to be answered. For example, are the Kirtland biota, exclusive of the Naashoibito, truly essentially similar to those of the Fruitland delta plain, but less abundant and diverse, or are there subtle but significant taxonomic or ecological differences influenced by the more inland position of the Kirtland biota that have yet to be discovered? If essential similarity does exist between the biota of the Fruitland and most of the Kirtland, what is the relationship of the inland Naashoibito biota to that of the rest of the Kirtland? Are the predecessors of the Naashoibito biota present in the Kirtland beneath it, or were important elements of the evolving Fruitland-Kirtland biota ecologically displaced suddenly by immigrants from other areas during the time of Naashoibito deposition? Is there an unconformity at the base of the Naashoibito and, if so, how significant is it in terms of apparent biological changes? Though there have been tentative attempts to provide answers to some of these questions (see discussions by Lehman, 1981; Lucas, 1981; Lucas et al., in press), the information necessary to do so completely is not yet available. The biota of the Fruitland and lower part of the Kirtland may seem to be adequately known, but there is still much work left to be done on some aspects of these biota.

Concluding remarks

In this section of the paper we have considered the stratigraphy, depositional environments, and paleontology of the Fruitland and lower Kirtland Formations in a small area in the southwestern San Juan Basin. Because lateral changes in lithofacies are typical of the Fruitland and individual coal, channel-sandstone, and shale units are not continuous for more than a few kilometers (Flores and Erpenbeck, 1982), the stratigraphic and facies subdivisions observed in the Bisti area are very probably not exactly duplicated elsewhere along the Fruitland outcrop belt. However, the information provided here and in papers by previous workers should make it possible to recognize the various delta-plain environments and associated biota wherever they occur within the Fruitland.

In our opinion, the most profitable avenue for future studies of Fruitland-Kirtland paleontology would involve comprehensive collection and accurate identification of additional fossil remains—especially microvertebrate, plant, and molluscan assemblages—coupled with precise placement of each fossil or assemblage within the stratigraphic and paleoenvironmental context of the local Fruitland-Kirtland section. Because of the time-transgressive nature of Fruitland-Kirtland deposition across the San Juan Basin, each local section represents a slightly different short segment of Late Cretaceous time. If the biota of each environment preserved in every area of Fruitland-Kirtland exposure can be accurately characterized, it will become possible not only to compare geographic variation within biota of the same environments, but also to determine temporal variation in the biotic constituents of each environment. That in turn would allow, within the constraints imposed by the degree to which these formations are exposed, the evolution of the communities that lived in each environment to be traced through several million years of Late Cretaceous time. We believe that the broad patterns of Fruitland-Kirtland paleontology have been established. What is needed now is an understanding of the details and local variations in the patterns, developed by means of comprehensive studies of restricted areas of Fruitland-Kirtland exposure and restricted parts of the Fruitland-Kirtland section.

Brackish-water microvertebrates

Introduction

During the course of this study a bulk sediment sample at one microvertebrate locality (BUNM 77-25) was collected, screen-washed, and examined for teeth and other small vertebrate remains. This locality is in the NE 1/4 ^{N}E 1/^{4} SE 1/4 sec. 31, T. 24 N., R. 13 W., approximately 0.8 km south of the Bisti Trading Post site and represents a brackish environment within the middle delta-plain interval of the Fruitland Formation. Details of the stratigraphy and descriptions of some invertebrates (bryozoan, crab, and the bivalve *Teredina)* were reported by Kues (1983). Processing of the bulk sample yielded about 20 kg of concentrate, which contained a total of 960 isolated vertebrate teeth along with more than 500 gar scales and numerous other postcranial fragments of a variety of vertebrates. Some observations on this assemblage are presented here in order to more completely characterize the paleontology of the Fruitland Formation within the Bisti area and to augment information on Fruitland microvertebrate remains derived from previous and continuing studies in other areas.

Relatively few studies of Fruitland and Kirtland microvertebrate remains based on screen-washing techniques have been accomplished compared to Campanian and Maastrichtian units in Wyoming and Montana. Clemens (1973) and Clemens et al. (1979) briefly discussed the mammals obtained from the University of Kansas collecting activities in 1962-1967. Clemens' samples containing mammals came from several localities in sections 28, 29, 32, 33, and 34, T. 24 N., R. 13 W. (data from Kues et al., 1977, via Clemens and the University of Kansas) within an interval ranging from approximately 12 m below the widespread coal bed chosen as the top of the Fruitland by many authors (Coal F of this paper), to approximately 17 m above this coal bed (Clemens, 1973: 162). Using our terminology, the upper level of Clemens' sampling interval would be near the upper boundary of the Fruitland; it would be considered within the lower shale member of the Kirtland by most workers.

In the most extensive study of Fruitland—Kirtland microvertebrates yet published, Armstrong-Ziegler (1978, 1980) reported a diverse fish, amphibian, reptilian, and mammalian fauna from three localities on the Navajo Reservation in T. 26 N., R. 16 W. near Cottonwood and Pinabeta Arroyos, approximately 32 km northwest of Bisti. Specimens from a fourth locality, in section 34, T. 24 N., R. 13 W. near Clemens' localities in the Bisti area, were collected by the University of Arizona and examined by Armstrong-Ziegler. The three Navajo localities were within the upper 15.2 m of the Fruitland, and the University of Arizona locality appears to be high in the Fruitland or possibly in the lower Kirtland. Armstrong-Ziegler's studies are important not only because of the large sample (more than 7000 specimens) collected, but also because she recognized distinctive assemblages of taxa that allowed determination of several different environments within the Fruitland.

More recently, a large screen-washing program has been initiated in the "Fossil Forest" area about 10 km southeast of Bisti (briefly reported by Rigby and Wolberg, 1980, 1983, and Wolberg and Rigby, 1981) from an interval including the upper third of the Fruitland and possibly part of the basal Kirtland, stratigraphically equivalent to the interval sampled by Clemens and Armstrong-Ziegler. Though work is still in progress, a large number of vertebrate teeth, including more than 800 mammalian teeth, have been collected from the "Fossil Forest" localities, and the study promises to contribute significantly to knowledge of Late Cretaceous paleontology of the San Juan Basin.

The assemblage of microvertebrate remains from locality BUNM 77-25 described below represents a lower level in the Fruitland than has previously been sampled by screen-washing techniques. The locality is about 30 m above the base of the Fruitland, about 20 m below the highest major coal bed (Coal F) used as the Fruitland—Kirtland boundary by Fassett and Hinds (1971) and others, and approximately 30-40 m below the persistent sandstone body that we use as the top of the Fruitland.

The fauna

In studying the assemblage from locality BUNM 77-25, we have concentrated primarily on teeth; work is still in progress on the postcranial remains of small vertebrates. Thus the list of taxa presented in Table 4 is preliminary and will no doubt be expanded as studies continue. The number of teeth of each taxon is indicated in order to show their relative abundance in this assemblage. In the following discussion, we briefly describe and comment on each element in the assemblage. The teeth of many of the smaller Fruitland vertebrates, especially the fish, have never been illustrated; that situation is partially remedied here as an aid to future workers.

TABLE 4—Taxa recovered by screen-washing a bulk sample at locality BUNM 77-25, middle delta-plain interval, Fruitland Formation. Number of specimens and percentage of total specimens of teeth are given for each taxon. * = number of fragments; number of individual teeth represented is probably one-quarter to one-third of the number of fragments.

Taxon	Specimens	Percentage
Teeth		
Chondrichthyes		
Hybodus sp.	4	0.4
Lonchidion selachos Estes	7	0.7
?*L. selachos* Estes	10	1.0
Myledaphus bipartitus Cope	74	7.7
Ptychotrygon aff. *triangularis* (Reuss)	1	0.1
Squatirhina sp.	7	0.7
Osteichthyes		
Amia cf. *uintaensis* (Leidy)	401	41.9
Amia sp.	7	0.7
Lepisosteus sp.	71	7.4
Paralbula cf. *casei* Estes	171	17.9
cf. *Pseudoegertonia*	67	6.9
Reptilia		
Leptochamops denticulatus (Gilmore)	1	0.1
Brachychampsa? sp.	34	3.6
Leidyosuchus sp.	3	0.3
Crocodilia indet.	56	5.8
Hadrosauridae	42*	4.4
Dromaeosauridae	2	0.2
Thescelosaurus? sp.	1	0.1
Mammalia indet.	1	0.1
Postcranial and other remains not represented by teeth		
Testudines		
"Baena" nodosa Gilmore		
Neurankylus eximius Lambe		
Adocus sp.		
Trionychidae indet.		
Reptilian egg-shell fragments		
Invertebrates		
Conopeum? sp. (Bryozoa)		
Xanthoidea? (Crustacea)		
Teredina sp. (Bivalvia)		

Slightly more than 10% of the teeth in this assemblage are chondrichthyan. Most of these are from *Myledaphus bipartitus* (Figs. 13.1-13.3), a dasyatid ray that is common in many Late Cretaceous non-marine units in western North America. Because the teeth of this species have been extensively described (e.g. Gilmore, 1916; Estes, 1964), no further comments are made here.

Several transversely elongate teeth (Fig. 13.4) ranging up to 11 mm in width are assigned to *Hybodus*, a hybodont shark. These teeth possess a single, large, slightly recurved central cusp, lack labial and lingual projections, and are ornamented by narrow but conspicuous ridges along the base. They resemble specimens of *Hybodus montanensis* described by Case (1978) from an estuarine environment in the Judith River Formation of Montana. Gilmore (1935, fig. 17) identified a tooth of similar shape, but apparently with a striated cusp, from the Kirtland Formation as a squatinid shark.

The small teeth of *Lonchidion selachos* (Figs. 13.5, 13.6), a hybodont shark, are minor elements in the Bisti assemblage, and were previously reported from the Fruitland by Kues et al. (1977) and Armstrong-Ziegler (1978, 1980). About half of the specimens are typical lateral teeth similar to those reported by Estes (1964) from the Lance Formation of Wyoming. Several specimens (e.g., Figs. 13.7, 13.8) show general similarity to *L. selachos*, but differ in the arcuate rather than straight main tooth axis. These may fall within the range of variation of *L. selachos*, but the assignment here is questioned because of the lack of good intermediate forms in the collections at hand. Two triangular teeth with single small cusps on each side of the large central cusp resemble symphyseal teeth of *L. selachos* described and illustrated by Estes (1964, fig. 2). The Fruitland specimens differ slightly in having a sharper and narrower primary cusp and a more pronounced lingual projection at the base of the crown. A single tip of a dorsal spine similar to that figured by Estes (1964, fig. 4b) and assigned by him to *L. selachos* is also present in the collections.

One small (2 mm wide), transversely elongate tooth (Figs. 13.9-13.11) represents the dasyatid ray *Ptychotrygon.* The crown is relatively low and bears a sharp central ridge with an elevated, rounded cusp, an additional lower ridge near the anterior and posterior margins of the crown, and a minor ridge on the anterior proboscoid extension of the crown. The base is divided into two equal areas by a central groove and in no way differs from the norm for the genus. The Fruitland specimen, assigned to *Ptychotrygon* aff. *triangularis,* is similar to *P. triangularis* as revised by McNulty and Slaughter (1972), especially in being ornamented by three prominent, well separated transverse ridges, but it differs in the sharper, non-corrugated shape of these ridges. McNulty and Slaughter (1972) discussed the species of *Ptychotrygon* and reported that the genus is a minor but ubiquitous element of fish faunas from Campanian and Maastrichtian units in Texas. The genus has also been reported in North America from the Turonian Carlile Shale of South Dakota (Cappetta, 1973) and the Tres Hermanos Formation in Socorro County, New Mexico (Baker and Wolberg, 1981; Baker et al., 1981), and is abundant in the late Campanian Pictured Cliffs Sandstone, San Juan Basin, New Mexico (Rigby and Clement, 1983). The species *P. triangularis* has been reported in New Mexico only from the early Campanian Point Lookout Sandstone in the southern San Juan Basin, where it occurs with *Scapanorhynchus raphiodon, Squalicorax kaupi, Odontaspis* sp., and other shark teeth (Kues et al., 1977; identifications by R. Estes). This is the first report of *Ptychotrygon* from the Fruitland Formation.

Several teeth of the orectolobid shark *Squatirhina* (Fig. 13.12) have the same general features as *S. americana* described by Estes (1964) from the Lance Formation, but differ from that species in possessing a narrower and sharper main cusp and a slightly sharper labial projection.

Osteichthyan fish dominate the Bisti assemblage. The gar *Lepisosteus* is represented by more than 500 partial to complete scales and by numerous teeth. Examination of the skull of the modern *L. osseus* aided the identification of Fruitland gar teeth. Modern species of gar possess at least two types of teeth. Marginal teeth are straight, sharply pointed cones that are somewhat swollen near the base. The base, which may extend from about one-third to two-thirds of the distance to the distal end, is conspicuously striated, in contrast to the smooth, unornamented tip. Most of the Bisti gar teeth are of this type (Fig. 13.13). A row of smaller teeth that are bluntly rounded and possess a nipple-like mound on the tip are situated along the inside upper edge of each dentary, paralleling the marginal teeth, in *L. osseus.* A few similar teeth (Fig. 13.15) are present in the Bisti collections. Interestingly, *Amia calva,* the modern bowfin, also possesses numerous teeth of this type, situated on the upper palatal region posterior to the marginal teeth near the front of the upper jaw. It has not been possible to distinguish these from similar teeth of *Lepisosteus;* thus the "nippled" teeth in the Bisti assemblage may represent *Amia, Lepisosteus,* or both. Ten teeth in the collections appear to represent still another tooth form of *Lepisosteus* (Fig. 13.14). These are identical to the marginal teeth described above, except that the smooth tips are flattened into sharp, lanceolate flanges. Although no teeth of this type were observed in *L. osseus,* Estes (1964: 46) mentioned the presence of such teeth in *L. spatula,* another modern species, though they are apparently lacking in the Cretaceous *L. occidentalis.*

Wiley (1976) assigned several fossil and modern gar species to the genus *Atractosteus,* including *L. spatula* and *L. occidentalis* mentioned above. Although no differences in tooth form between *Lepisosteus* and *Atractosteus* were noted by Wiley, *Atractosteus* does possess enlarged dermopalatine "fangs." Fruitland gar remains are assigned to *Lepisosteus* rather than *Atractosteus* because there is no evidence of unusually large teeth in the collections and because fragments of probable dermopterotic and parietal bones show extensive enameloid patterns that are more characteristic of the Cretaceous *L. opertus* than *A. occidentalis.*

Three distinct types of teeth referrable to *Amia* were observed in the Bisti assemblage. A few smooth, gently curved, uncompressed teeth are identical to marginal teeth of the modern *A. calva.* Smaller, blunt teeth with apical nipples, possibly from the palatal area of *Amia,* have been discussed above. The third type includes more than 40% of all teeth in the assemblage. They are sharp, highly to moderately compressed, gently curved, elongate to subtriangular teeth with a sharp carina on each side that extends from the base to the tip (Figs. 13.18, 13.19). Teeth of this type from other Fruitland localities were recorded as *Amia* cf. *uintaensis* by Kues et al. (1977), based on identification by R. Estes. Boreske (1974, fig. 18) illustrated a transverse section through the mandible of *A. uintaensis* that indicated several rows of these teeth on the upper inside edge of the mandible, below the much larger conical marginal teeth. Larger specimens of these carinate teeth tend to be blunter and more inflated than smaller specimens and appear superficially similar to small, unornamented crocodilian teeth. Several *Amia* vertebrae were also present in the collections from locality BUNM 77-25.

The small (up to 5 mm in diameter), button-shaped teeth of *Paralbula* cf. *casei* (Figs. 13.16, 13.17) are among the most common teeth in the Bisti assemblage. They have a circular to slightly elongate crown that is generally gently convex across its occlusal surface and ornamented by numerous fine, pustulose, radially oriented reticulations. Worn specimens are virtually smooth. The enamel extends around the periphery

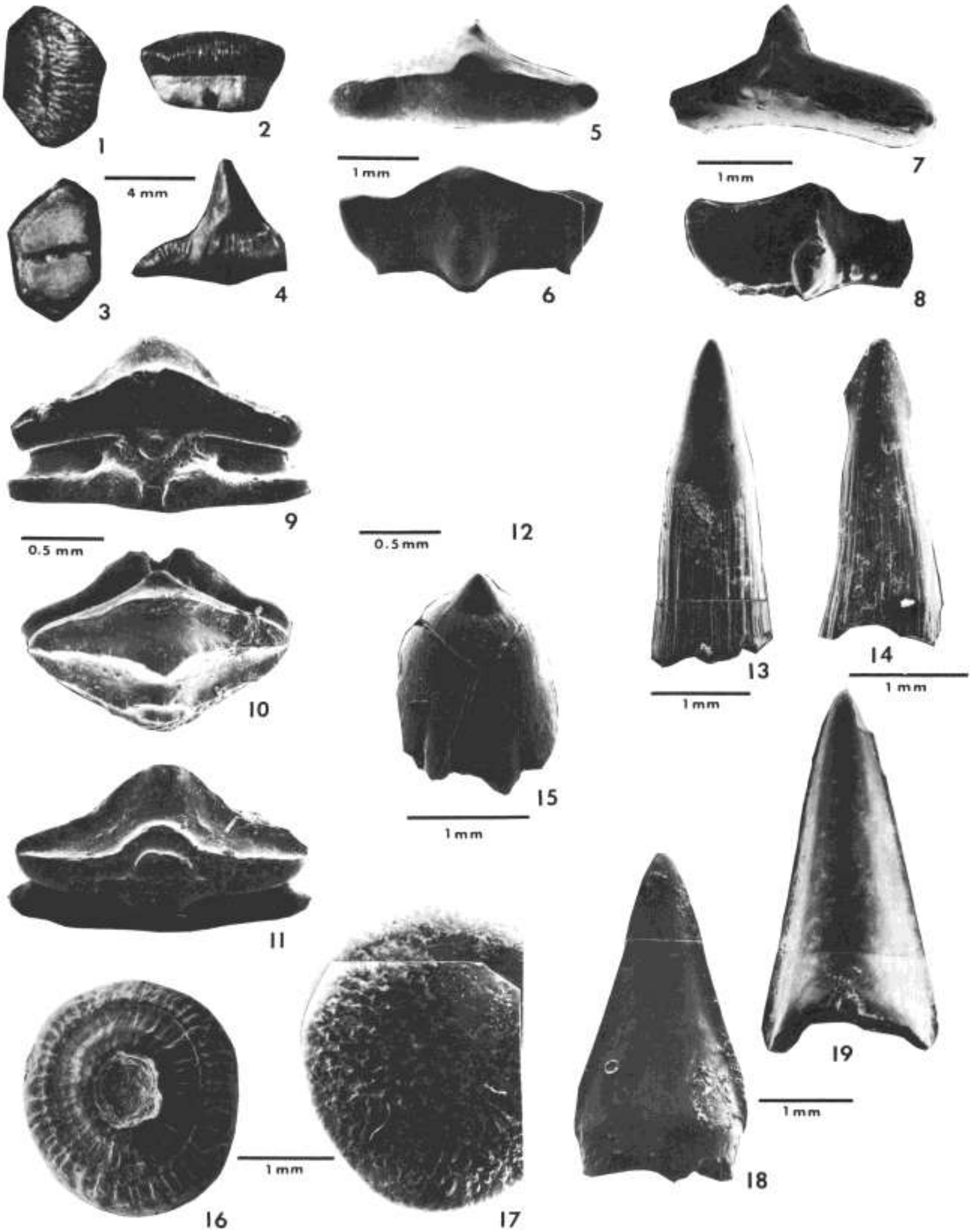

FIGURE 13—Specimens from Fruitland Formation, locality BUNM 77-25. **1–3**, *Myledaphus bipartitus* Cope, occlusal (1), side (2), and basal (3) views of a single tooth, FKK-086. **4,** *Hybodus* sp., labial view of a large tooth, FKK-088. **5, 6,** *Lonchidion selachos* Estes, occlusal (5) and labial (6) views of a lateral tooth, FKK-090. **7, 8,** *Lonchidion selachos* Cope ?, occlusal (7) and labial (8) views of a lateral tooth (broken at one end), FKK-092. **9–11,** *Ptychotrygon* aff. *triangularis* (Reuss), posterior (9), occlusal (10), and anterior (11) views of a single tooth, FKK-094. **12**, *Squatirhina* sp., oblique labial view of a tooth, FKK-095. **13, 14**, *Lepisosteus* sp., side views of a typical marginal tooth, FKK-097 (13), and of a tooth with a lanceolate tip, FKK-099 (14). **15**, *Lepisosteus*? sp., side view of a blunt, "nippled" tooth, FKK-101. **16, 17**, *Paralbula* cf. *casei* Estes, basal view of a small tooth, FKK-104 (16), and occlusal view of part of a large tooth, FKK-103 (17) showing reticulated, pustular ornamentation. **18, 19**, *Amia* cf. *uintaensis* (Leidy), labial view of a typical tooth, FKK-120 (18), and lingual view of a relatively elongate tooth, FKK-121 (19).

to form a narrow, striated basal rim, and the root and large pulp cavity are prominently situated in the center of the basal surface. Armstrong-Ziegler (1978, 1980) recorded *Paralbula* from estuary and lowland river environments within the Fruitland. Kues (1983) tentatively identified smooth specimens of *P.* cf. *casei as Anomaeodus,* but true representatives of that genus have not been observed in the Fruitland. *Anomaeodus* or a closely related genus does occur in the marine sediments of the Mancos Shale in the Rio Puerco area of central New Mexico.

According to R. Estes, who examined a few typical specimens (Lucas, pers. comm. 1983), small, highly worn, peglike to pustular teeth in the Bisti assemblage (Figs. 14.1-14.4) are comparable to the teeth of the phyllodont teleost *Pseudoegertonia.* These teeth have a relatively narrow cylindrical base with a single central pulp cavity indicated by a prominent circular hole. The crown expands rapidly above the base to form a relatively high, rounded platform that is flattened or slightly convex on the occlusal surface. The height of the crown varies from about equal to the diameter (1-3 mm) to somewhat less, depending on the degree of wear. The periphery of the occlusal surface is round in most specimens, but extremely worn teeth have a low crown and an angular periperal margin. Faint striations are present along the sides of the upper surface in some specimens. As with the related phyllodont *Paralbula* cf. *casei,* in life numerous closely packed, successionally stacked teeth were situated on basibranchial tooth plates.

As far as we have been able to determine, teeth of this type have not been reported previously from the Fruitland or any other Late Cretaceous non-marine unit in North America. Estes (1969) discussed and illustrated the teeth of the type species, *P. straeleni,* from the Paleocene of Africa. The African teeth are larger than the Fruitland specimens and possess a rather sharply pointed occlusal surface on the expanded crown. It is possible that the Fruitland teeth originally had a similar shape, with wear accounting for the flatly rounded surfaces observed in the available specimens. Alternatively, these teeth may represent an undescribed taxon of phyllodont fish.

Reptilian teeth comprise about 15% of the teeth in this assemblage; most of these are crocodilian. However, a single tricusped tooth about 2 mm high is referrable to the lizard *Leptochamops denticulatus* (Fig. 14.5). This tooth is somewhat spatulate and the tip flares to a slightly greater diameter than the shaft. Estes (1964) described several teiid lizards from the Lance Formation as having tricusped teeth, but most of these have expanded bases, whereas *L. denticulatus* possesses relatively narrow, cylindrical teeth. Armstrong-Ziegler (1980) reported *L. denticulatus* only from an upland, fresh-water facies in the Fruitland, at her locality D, within the study area.

A wide variety of crocodilian teeth, probably representing several genera, are present in the assemblage, along with numerous osteoscutes. Blunt, somewhat compressed, striated crocodilian teeth from the Fruitland and Kirtland Formations have been assigned to *Brachychampsa* by Gilmore (1916) and Armstrong-Ziegler (1980) based on similarity to the teeth of *B. montanensis,* described from a nearly complete skull from the Hell Creek Formation of Montana (Gilmore, 1911). Here, numerous striated teeth having a variety of non-conical shapes are assigned questionably to *Brachychampsa.* A few of these teeth (e.g., Fig. 14.6) are relatively large and closely approximate in size and shape the tooth illustrated by Gilmore (1911, fig. 1). Others are equally large (up to 8 mm in length), but are much flatter, with a very gently convex occlusal surface (Figs. 14.7, 14.9, 14.12). Many of the teeth are broadly and bluntly triangular in profile and laterally compressed (Fig. 14.8), but are much smaller than the *Brachychampsa* tooth illustrated by Gilmore (1911). Some others are laterally compressed and higher than the previously mentioned type. All are carinate to a minor degree. Whether all of these teeth belong to a single crocodilian species is uncertain, as tooth-bearing crocodilian jaw remains have not been reported from the Fruitland, and variation of teeth within an individual animal or within a single species thus cannot be ascertained.

These teeth were compared with teeth in several jaw fragments of *Allognathosuchus* from the Paleocene Nacimiento Formation of the San Juan Basin. The teeth of this genus may vary from rather flatly rounded to nearly conical within a single jaw and closely resemble some of the teeth assigned here to *Brachychampsa?.* Our impression is that it is impossible to distinguish between *Brachychampsa* and *Allognathosuchus* on the basis of isolated teeth alone. It is of interest to note that a few large molluscivorous teiid lizards, such as *Tupinambis,* also possess differentiated teeth, including low, blunt, heavily striated teeth at the back of each jaw. Examination of a Recent skull of *Tupinambis* revealed that their crushing teeth are remarkably similar to some of the smaller teeth in the Bisti assemblage assigned to *Brachychampsa?.* While it is highly unlikely that any of the Bisti teeth belong to *Tupinambis* [its fossil record extends back only to the Oligocene (Romer, 1966) and none of the known Cretaceous teiids have teeth of this type], the presence of such similar teeth in unrelated reptiles suggests that caution should be used in identifying taxa on the basis of isolated teeth alone.

Fragments of three large, conical teeth appear to be *Leidyosuchus.* They are distinguished by having smooth or very faintly ridged enamel and lacking the striations and ridges present on teeth of similar size assigned to Crocodilia, type 2. In general, these teeth closely resemble the more elongate teeth of L. *canadensis,* described and illustrated by Lambe (1907, pl. 2, figs. 4, 6).

The remaining crocodilian teeth are minute to medium-sized and more or less conical in shape. Two distinct types occur, which we prefer not to assign to a genus at the present time. Most of these teeth (Crocodilia, type 1) are small (2-4 mm), carinate, somewhat compressed, and moderately recurved, producing a convex labial and gently concave lingual surface. Their shape varies from relatively low and subtriangular in profile to relatively elongate (Fig. 14.10), but the pattern of striations along the length of these teeth is constant. The striations are relatively strong, straight, evenly rounded ridges, some of which bifurcate to-

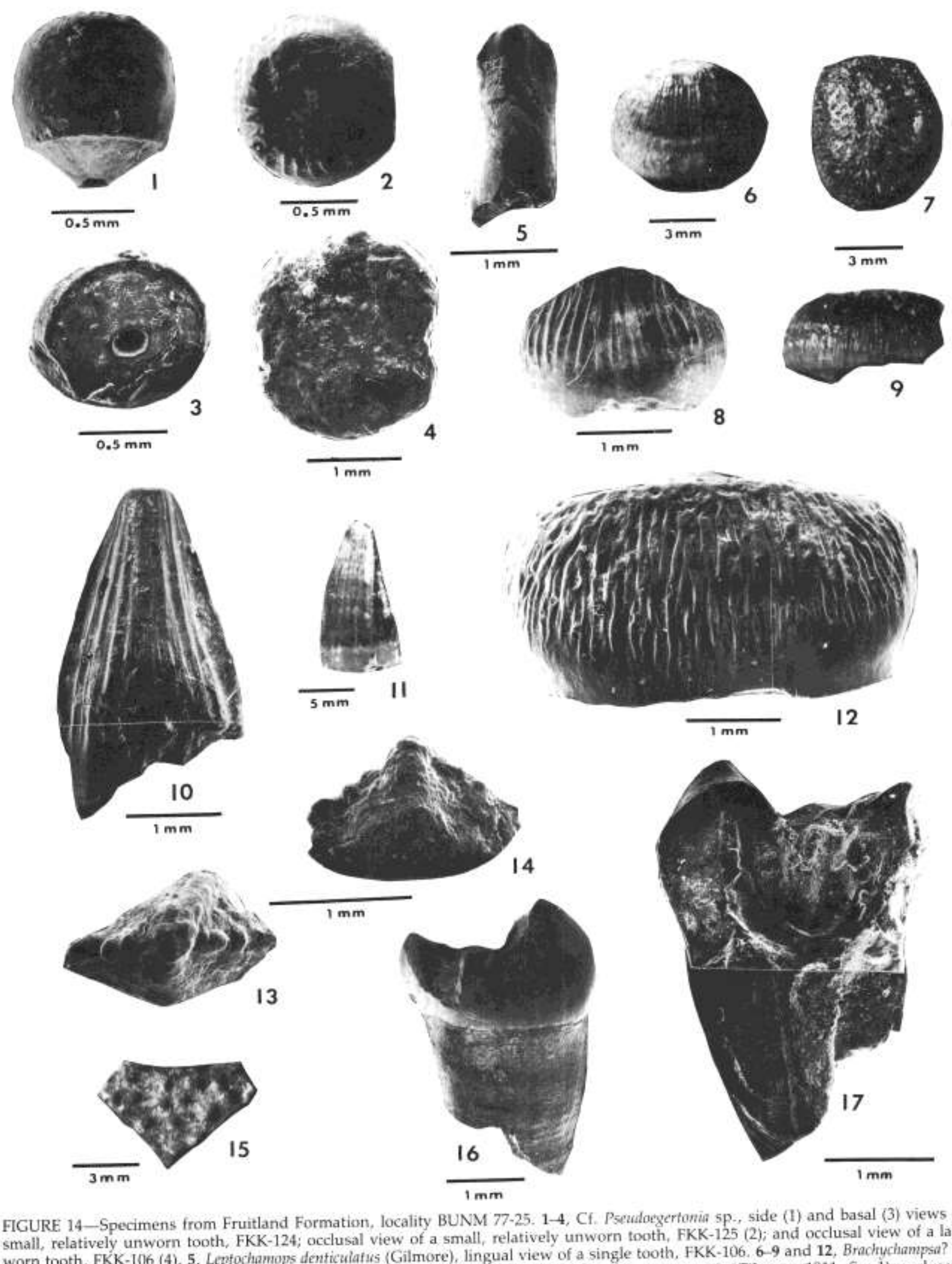

FIGURE 14—Specimens from Fruitland Formation, locality BUNM 77-25. **1–4**, Cf. *Pseudoegertonia* sp., side (1) and basal (3) views of a small, relatively unworn tooth, FKK-124; occlusal view of a small, relatively unworn tooth, FKK-125 (2); and occlusal view of a large, worn tooth, FKK-106 (4). **5**, *Leptochamops denticulatus* (Gilmore), lingual view of a single tooth, FKK-106. **6–9** and **12**, *Brachychampsa*? sp., oblique side view of a large, bluntly rounded tooth, FKK-107 (6), similar to tooth of *B. montanensis* (Gilmore, 1911, fig. 1); occlusal (7) and side (9) views of a large flat tooth, FKK-108; side view of a small blunt tooth, FKK-109 (8); and side view of a small flat tooth, FKK-128 (12). **10, 11**, Crocodilia indet., lingual view of a "type 1" tooth, FKK-111 (10), and side view of a large "type 2" tooth, FKK-115 (11), showing pronounced carina. **13, 14**, *Thescelosaurus*? sp., occlusal (13) and side (14) views of a single tooth, FKK-117. **15**, External surface of a dinosaur(?) egg-shell fragment, FKK-119. **16, 17**, Mammalia indet., labial(?) view of a tooth fragment, FKK-118 (16), showing crown and single root; and cross-section view along axis of the same tooth fragment (17), showing single pulp cavity in root that bifurcates about at level of crown.

ward the base. Finer striae are present between some of the major striations. In many specimens small striae curve onto the carinae, especially near the base, creating a distinctive pattern of carina ornamentation. The more elongate teeth of this type generally lack striations on the carinae. Wear facets were observed near the tip on both the convex and concave surfaces of a few of the teeth. Collectively, these teeth cannot be assigned to any crocodilian genus previously reported from the Fruitland or Kirtland. In shape they resemble, but are more finely striate than, teeth from the Lower Cretaceous of Spain questionably assigned by Estes and Sanchiz (1982) to the mesosuchian family Pholidosauridae. Pholidosaurids have also been reported from the Turonian—Santonian of North America (D. A. Russell, 1975).

Several larger teeth (Crocodilia, type 2), including a portion of one measuring 13 mm in height, show pronounced broad ridges along the tooth, with the enamel surface being finely striate or thrown into minute anastomosing folds both on and between the ridges (Fig. 14.11). These are probably from a different crocodilian than the much smaller teeth described as Crocodilia, type 1, but they do resemble the smaller teeth in having finely striate carinae.

Dinosaur teeth are relatively uncommon in this assemblage. Fragments of hadrosaur teeth are most numerous, but all fragments in the assemblage could have easily come from a single individual. Small portions of the serrated cutting edges of small carnivorous dinosaurs are assigned to the Dromaeosauridae. The larger of the two available fragments has rounded, slightly spatulate serrations numbering about 17-18/ 5 mm; the serrations on the smaller fragment are tiny and number about 9/mm. The size and shape of these serrations are identical to those observed in some complete teeth in the UNM collections (e.g., B-568) from the Fruitland elsewhere within the study area (see Lucas et al., in press, fig. 2J). These teeth are relatively strongly recurved and possess fine serrations on the anterior edge and larger ones on the concave posterior edge. As the variations in serration patterns and other features of dromaeosaur teeth within an individual are not well documented, we follow Lucas et al. (in press) in not assigning these teeth to a particular genus at the present time.

A single small tooth in the collections displays a broadly triangular profile, a large central cusp at the apex, and three to four smaller denticules along the anterior and posterior ridges (Figs. 14.13, 14.14). Viewed from above, the tooth is somewhat rhomboidal, with low, rounded ridges sloping away from, and nearly perpendicularly to, the denticulate crest. This tooth resembles one described and illustrated by Sahni (1972, fig. 9E, F) as the hypsilophodont dinosaur *Thescelosaurus* cf. *neglectus* from the Judith River Formation. However, the tooth at hand is smaller (1.6 mm long compared to 2.3 mm for the tooth illustrated by Sahni) and possesses a less acute apex than the Judith River tooth. We assign this tooth questionably to *Thescelosaurus;* more and better preserved specimens are required to more accurately determine its affinities. If it does represent *Thescelosaurus*, this is the first report of that dinosaur in the Fruitland.

In contrast to the assemblages higher in the Fruitland, only one mammalian tooth is present in the Bisti assemblage (Figs. 14.16, 14.17). It is a longitudinal half of a small tooth having a single root, a pulp cavity that bifurcates, and a crown bearing prominent cusps on the anterior and posterior ends. The broken base of a smaller cusp is present along the lateral margin of the tooth, immediately in front of the posterior(?) cusp. Because of the fragmentary nature of this tooth, generic identification was not attempted.

In addition to the teeth described above, a large number of non-dental skeletal elements were present in the sample, especially turtle-shell fragments (Table 4). Of special interest is the occurrence of a few small reptilian egg-shell fragments. The best preserved fragments are very gently curved and display a distinctive ornamentation consisting of isolated, generally widely spaced, relatively sharp circular nodes about 0.75-1 mm in diameter across the convex surface (Fig. 14.15). The internal (concave) surface lacks nodes and is relatively smooth, with numerous minute pores and short channels across a fibrous or prismatic structure creating a very finely reticulate pattern. These shell fragments resemble "Class B" specimens from the North Horn Formation of Utah (Jensen, 1966) and Judith River Formation of Montana (Sahni, 1972). The distribution and spacing of the nodes are closest to the shell illustrated by Jensen (1966) in fig. 2 of pl. 3, though the density of small pits between the nodes is far less and the nodes are larger in the Bisti specimens. Sahni (1972) believed shells with similar sculpture to be dinosaurian.

Discussion

This assemblage consists primarily of fish remains. Nearly three-quarters of the teeth are of osteichthyans, mainly *Amia*, with another 11% representing various chondrichthyans, chiefly the ray *Myledaphus.* Based on tooth counts, reptiles (predominantly crocodilians) contribute about 15% of the total, although reptilian abundance was undoubtedly higher than is indicated by the teeth because turtle-shell fragments are the major postcranial skeletal elements present. No amphibian teeth and only a single mammalian tooth were observed. The assemblage is dominated by the remains of stream-dwelling organisms; about 95% of the teeth are from fish and reptiles that lived an aquatic existence. There is little evidence of extensive transportation of skeletal elements prior to burial; even the most delicate teeth are in most cases unbroken and uneroded. This assemblage appears to reflect accurately the major constituents of a local stream-dwelling community, with only slight introduction of elements derived from terrestrial communities.

Together, *Amia* and *Lepisosteus* contribute almost 50% of the teeth. Though primarily found in fresh-water environments today, some species of modern gars enter brackish and marine waters, ranging from estuaries, bayous, and salt marshes to the open marine waters of the Gulf of Mexico (Suttkus, 1963; Walden, 1964; Lee et al., 1980). *Amia calva,* the modern bowfin, prefers lowland waters, mainly warm, sluggish rivers and shallow, weedy waters of bays, inlets, and lagoons (Walden, 1964). The abundance of *Lepisosteus* and *Amia* remains in this Fruitland channel is thus consistent with either a fresh- or brackish-water environment, as is the presence of numerous turtle and crocodilian bone fragments. *Myledaphus bipartitus* was interpreted by Estes (1964) as possibly a permanent member of a fresh-water community in the Lance Formation; the species is also present in estuarine to fresh-water environments of the Judith River Formation (Case, 1978), and was interpreted as euryhaline by Armstrong-Ziegler (1980). The small shark *Lonchidion* may have been fully adapted to fresh-water conditions (Estes, 1964), but was reported also from estuarine environments in the Fruitland (Armstrong-Ziegler, 1980).

Several elements of the Bisti assemblage indicate that the environment was slightly brackish. Modern relatives of *Paralbula* are unknown in fresh water (Estes, 1964), and the genus appears to have been euryhaline (Armstrong-Ziegler, 1980) or an occasional migrant into rivers and streams from marine environments (Estes and Berberian, 1970). The chondrichthyans *Hybodus* and *Ptychotrygon* are known from fully marine environments in the Cretaceous (Baker and Wolberg, 1981; McNulty and Slaughter, 1972), and both genera were recorded from estuarine environments in the Judith River Formation (Case, 1978). *Squatirhina* is a member of a group with no modern fresh-water representatives (Estes, 1964) and occurs only in environments interpreted as estuarine in the Fruitland (Armstrong-Ziegler, 1978, 1980). Amphibians are conspicuous in assemblages of the Lance and Hell Creek Formations and are interpreted as having lived in freshwater conditions (Estes and Berberian, 1970); modern amphibians are almost entirely confined to fresh water (Estes, 1964). Armstrong-Ziegler (1980) found amphibian remains to be present only in assemblages lacking significant numbers of euryhaline fish in the Fruitland. The absence of amphibians in the Bisti assemblage, as in two Fruitland assemblages interpreted as estuarine by Armstrong-Ziegler (1980), provides additional evidence that the environment considered here was brackish rather than fresh water. Finally, the presence of bryozoan and crab remains and of the euryhaline bivalve *Teredina* in the Bisti assemblage also suggests brackish conditions (Kues, 1983). Thus, we interpret this assemblage as representing the remains of an aquatic community that lived in a stream or distributary of low (probably 5% or less) salinity and low current velocity near the distal margin of the middle delta plain, a few kilometers inland from the Pictured Cliffs shoreline.

A significant number of fish in this assemblage possessed batteries of flattened teeth, probably an adaptation for crushing small invertebrates that served as a major food source. Teeth of *Myledaphus, Paralbula,* and cf. *Pseudoegertonia* together constitute more than 35% of the fish teeth present in the sample. It has also been suggested that *Lonchidion* may have fed on arthropods (Estes, 1964), and some modern brackish-water gar species frequently consume crabs (Suttkus, 1963). It is likely that the community to which these fish belonged also included a profuse aquatic arthropod fauna that, except for sparse remains of crabs (Armstrong-Ziegler, 1980; Kues, 1983), is largely unpreserved or unrecognized in Fruitland sediments.

The Bisti assemblage is not closely similar to Armstrong-Ziegler's (1978, 1980) "Locality D" fauna, which was collected from the Fruitland about 5 km east of Bisti. She interpreted that assemblage, which is poorly diverse but relatively rich in amphibians, as representing a fresh-water stream or pond in a relatively upland area rather far from the shoreline. The major constituents of the Bisti assemblage, however, are very similar to those present at Armstrong-Ziegler's (1980) "Locality C," about 30 km northwest of Bisti, which she interpreted as a moderately inland, lowland river environment. More detailed comparison is not possible because the relative abundances of the various taxa at "Locality C" were not given by Armstrong-Ziegler.

The localities within the study area from which Clemens obtained mammals appear to represent a range of levels within the Fruitland and lower Kirtland, from the inner part of the middle delta plain (Coal C to Coal F interval) through the upper delta plain to the flood plain. The paucity of mammals in the Bisti assemblage and at "Locality C," as well as the low number of remains from other constituents of terrestrial communities, accurately reflect the much lower abundance of these groups on the middle delta plain, relative to the upper delta plain, indicated in Tables 2 and 3.

Few general conclusions result from this study of a single Fruitland microvertebrate assemblage. Although there is some evidence that closely similar assemblages are present in the Fruitland in other areas, local variation in stream-dwelling faunas within the various parts of the Fruitland delta system remains to be adequately documented. Analysis of numerous microvertebrate assemblages through each interval and with good regional distribution within the Fruitland and Kirtland Formations is required before the microvertebrate fauna becomes completely known and before detailed and accurate interpretation of the paleoecology of the biotic communities preserved in these two formations can be made.

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Depositional environments of the Naashoibito Member of the Kirtland Shale, Upper Cretaceous, San Juan Basin, New Mexico

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Abstract

The Upper Cretaceous Naashoibito Member of the Kirtland Shale comprises the highest dinosaur-bearing strata on the western side of the San Juan Basin and consists of four principal lithofacies. The yellow-conglomerate facies is cross-stratified, limonitic, medium- to coarse-grained, conglomeratic litharenite and occurs as a single, extensive, sheet-like bed generally less than 2 m thick. This facies was subject to widespread erosional deflation prior to burial, and represents deposition in braided streams. The white-sandstone facies is composed of fine- to very coarse-grained, smectite-rich subarkose to sublitharenite and occurs in laterally continuous units averaging 5 m in thickness. This facies is marked by gently inclined, clay-mantled accretionary surfaces and is locally incised through the yellow-conglomerate facies. A low-sinuosity meandering-stream depositional environment is indicated for the white-sandstone facies. Both the yellow-conglomerate and white-sandstone facies contain abundant silicic and intermediate volcanic detritus. The banded purple-mudstone facies consists of sandy and silty smectitic claystone marked by cyclic light-gray and purple color banding. This facies represents freely drained floodbasin deposits in which well-differentiated soils had repeatedly developed. The drab-mudstone facies comprises olive-green, brown, and dark-gray silty claystone accumulated as slackwater and overbank deposits in waterlogged areas in, and adjacent to, stream channels. Sedimentological evidence suggests a fluctuating hydrological regime and a seasonally dry climate during deposition of the Naashoibito Member. The Naashoibito bears a vertebrate fauna of Lancian age (late Maastrichtian) and is genetically equivalent to the McDermott Member of the Animas Formation which is exposed along the northern side of the San Juan Basin. Correlative strata in intervening areas were removed by erosion prior to deposition of the Ojo Alamo Sandstone.

Introduction

After almost eighty years of work by stratigraphers and paleontologists, the nature and position of the Cretaceous-Tertiary boundary in continental sediments of the San Juan Basin continues to be a matter of debate. Not only is there disagreement over current interpretations (e.g. Lindsay, Butler, and Johnson, 1981; Lucas and Schoch, 1982), but also over interpretations of the statements of previous authors (e.g. Fassett, 1973; Clemens, 1973). Baltz, Ash, and Anderson (1966), Fassett (1973), and Clemens (1973) have all thoroughly reviewed the history of the stratigraphic nomenclature of the deposits straddling the Cretaceous-Tertiary boundary, and interpretations of the placement of the boundary and of presumed unconformities in the section.

While much has been written on the stratigraphy and paleontology of these deposits, there have been few attempts to analyze them from a genetic standpoint. Powell's (1973) work on the Ojo Alamo Sandstone is a notable exception. The present study includes a description of the lithofacies of the uppermost part of the Kirtland Shale (Naashoibito Member) and an interpretation of the environments under which they accumulated. A better understanding of the depositional environments and provenance of these sediments, combined with what is known about the tectonic and biologic setting under which they accumulated, may help resolve some of the remaining questions about the Cretaceous-Tertiary boundary in the San Juan Basin.

Acknowledgments—Without the excellent work by U.S. Geological Survey stratigraphers such as Clyde Bauer, John Reeside, Harley Barnes, and Elmer Baltz, the interpretation presented here would not have been possible. This study is built largely on the foundation laid by these geologists, and I gratefully acknowledge their contributions. I would also like to thank Wann Langston, Jr., Gary Kocurek, and Everett H. Lindsay for reviewing various versions of this paper.

Placement of the Cretaceous—Tertiary boundary

Currently, most authors agree that the systemic boundary should be placed at or near the contact between the Ojo Alamo Sandstone and the underlying Kirtland Shale (Figs. 1, 2). Some authors (e.g. Powell, 1973) have cited the occurrence of dinosaur bones in the lower part of the Ojo Alamo as evidence for placing the boundary somewhere within this unit. Others (e.g. Lucas, 1981) have discounted these remains as having been reworked from underlying deposits. During fieldwork for this study, I found several nodosaur osteoderms and an indeterminate dinosaur rib fragment in situ one meter above the base of the Ojo Alamo on De-Na-Zin Wash (NW 1/4 ^{N}W 1/4 sec. 17 T. 24 N., R. 11 W.). These remains do not appear any more abraded than those typically found in the Naashoibito, but nothing short of articulated dinosaur remains could securely demonstrate a Cretaceous age for part of the Ojo Alamo.

In contrast, pollen (Anderson, 1960; Baltz et al., 1966), mammalian fossils (Rigby and Lucas, 1977), and intertonguing relationships (Baltz et al., 1966) confidently establish much of the upper part of the Ojo Alamo as Paleocene in age. It seems useful and prudent, therefore, to continue the practice of drawing the systemic boundary at the contact between the Ojo Alamo Sandstone and the Kirtland Shale.

Stratigraphic nomenclature

Powell (1973) and Lindsay et al. (1978, 1981) include the uppermost member of the Kirtland Shale, the Naashoibito Member of Baltz et al. (1966), within the Ojo Alamo and thus place the Cretaceous—Tertiary boundary within the Ojo Alamo. On the basis of profound lithologic and paleontologic similarities, however, the Naashoibito should be retained as part of the Kirtland Shale (see below). All recent U.S. Geological Survey mapping in this region includes sediments of the Naashoibito with those of the Kirtland Shale, whether or not they are set apart as a separate member. Moreover, the Naashoibito has in several places been markedly thinned, and in other places completely removed, by erosion prior to deposition of the Ojo Alamo (see Baltz et al., 1966; below). Stratigraphic relationships in the northwestern part of the San Juan Basin reveal that the Naashoibito and correlative deposits are genetically unrelated to the Ojo Alamo (see below). Thus, it is advisable to continue using without modification the stratigraphic nomenclature proposed by Baltz et al. (1966) for deposits in this region (Fig. 2).

The Cretaceous—Tertiary unconformity

Aside from the precise placement of the Cretaceous—Tertiary boundary and slight differences in stratigraphic nomenclature, the existence and magnitude of a hiatus represented by the unconformable base of the Ojo Alamo Sandstone is a debated issue. Based on the deep channeling (see Baltz et al., 1966) and regional angularity (see Fassett and Hinds, 1971) of the unconformity, it would seem to represent a substantial hiatus. Conversely, absolute dates on ashes in the Kirtland Shale (Lindsay et al., 1978), magnetostratigraphy (Lindsay et al., 1978; Lindsay et al., 1981), and the vertebrate fauna of the Naashoibito (Lehman, 1981) suggest that the hiatus is relatively small. The absolute dates on ashes (Brookins and Rigby, 1982), magnetostratigraphy (Alvarez and Vann, 1979), and vertebrate fauna (Lucas, 1981) have, however, all been disputed or interpreted differently to support a hiatus of long duration. Following is an attempt to reconcile these opposing viewpoints.

The Naashoibito Member

The Naashoibito Member of the Kirtland Shale is exposed only on the southwestern side of the San Juan Basin, at the heads of Hunter Wash, Willow Wash, Alamo Wash, and De-Na-Zin Wash (Fig. 1). This outcrop extends laterally about 30 km. Bauer (1916), Reeside (1924), and Baltz et al. (1966) have mapped the upper part of the Kirtland and Ojo Alamo in this area, and described and measured over 30 stratigraphic sections. Consequently, there is no need for additional gross stratigraphic work. Instead, using the measured sections of these authors as a framework, I have attempted to trace individual strata within the Naashoibito between outcrops (Fig. 3). I found it necessary to measure only a few additional full sections between those already published to complete the cross section presented here (Figs. 3, 4). To this I have added the stratigraphic position of important vertebrate fossils collected from the Naashoibito. Additional small-scale sections representative of each of the major lithofacies of the Naashoibito were measured; they are located on the restored cross section. The Naashoibito Member in this region exhibits four major lithofacies, in relative order of abundance volumetrically: a clay-rich white-sandstone facies, a banded purple and gray-mudstone facies, a yellow-conglomerate facies, and a drab-mudstone facies. These lithofacies are not confined to the Naashoibito, but occur also in underlying parts of the Kirtland Shale and in the overlying Ojo Alamo and Nacimiento Formations. The Naashoibito Member is, however, a recognizable and mappable stratigraphic unit because it is bounded above and below by erosional surfaces.

White-sandstone facies

The white-sandstone facies of this report (Figs. 59) includes strata described by Baltz et al. (1966) as soft, white-weathering sandstone with ferruginous "cannonball" concretions of the upper part of the Naa-

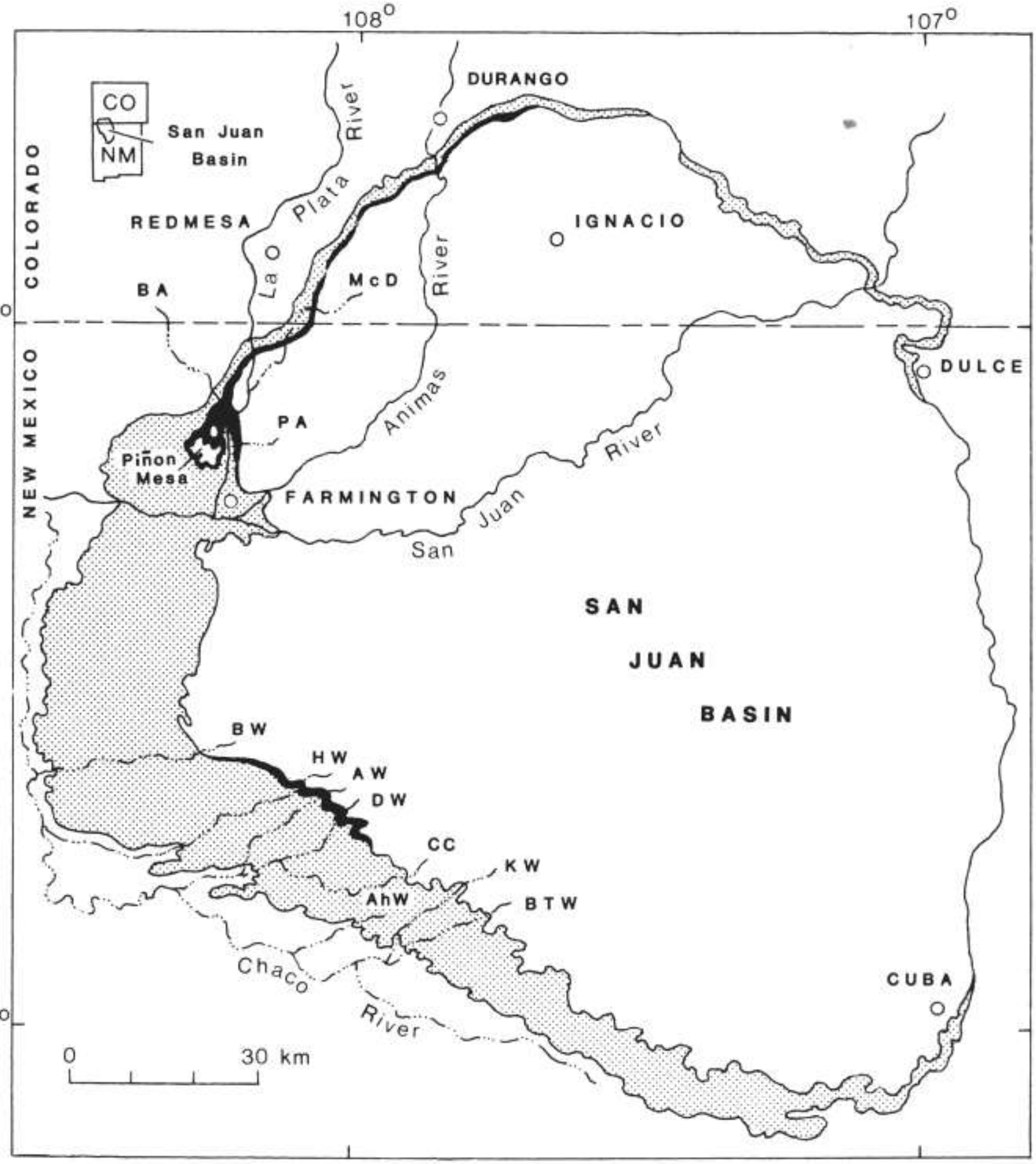


FIGURE 1—The San Juan Basin of northwestern New Mexico and southwestern Colorado showing the outcrop belt of the combined Upper Cretaceous Fruitland and Kirtland Formations (gray). The McDermott Member of the Animas Formation (north of the San Juan River) and the Naashoibito Member of the Kirtland Shale (south of the San Juan River) are shown in black. **AW** = Alamo Wash, **AhW** = Ah-She-Sle-Pah Wash, **BA** = Barker Arroyo, **BW** = Brimhall Wash, **BTW** = Betonnie–Tsosie Wash, **CC** = Coal Creek, **DW** = De-Na-Zin Wash, **HW** = Hunter Wash, **KW** = Kimbetoh Arroyo, **McD** = McDermott Arroyo, **PA** = Pickering Arroyo. Geology adapted from O'Sullivan and Beikman (1963) and Fassett and Hinds (1971).

CHRONOSTRATIGRAPHY		LITHOSTRATIGRAPHY		BIOSTRATIGRAPHY	
PALEOCENE	Danian	NACIMIENTO FORMATION		PUERCO FAUNA	Puercan
		OJO ALAMO SANDSTONE			
LATE CRETACEOUS	Maastrichtian	KIRTLAND SHALE	Naashoibito Member	ALAMO WASH LOCAL FAUNA	Lancian
			Upper Shale Member	HUNTER WASH LOCAL FAUNA	Edmontonian
			Farmington Sandstone Member		
	Campanian		Lower Shale Member		Judithian
		FRUITLAND FORMATION			

FIGURE 2—Stratigraphic-nomenclature chart for rocks exposed in the Ojo Alamo region (adapted from Baltz et al., 1966; Lehman, 1981; Lucas, 1981).

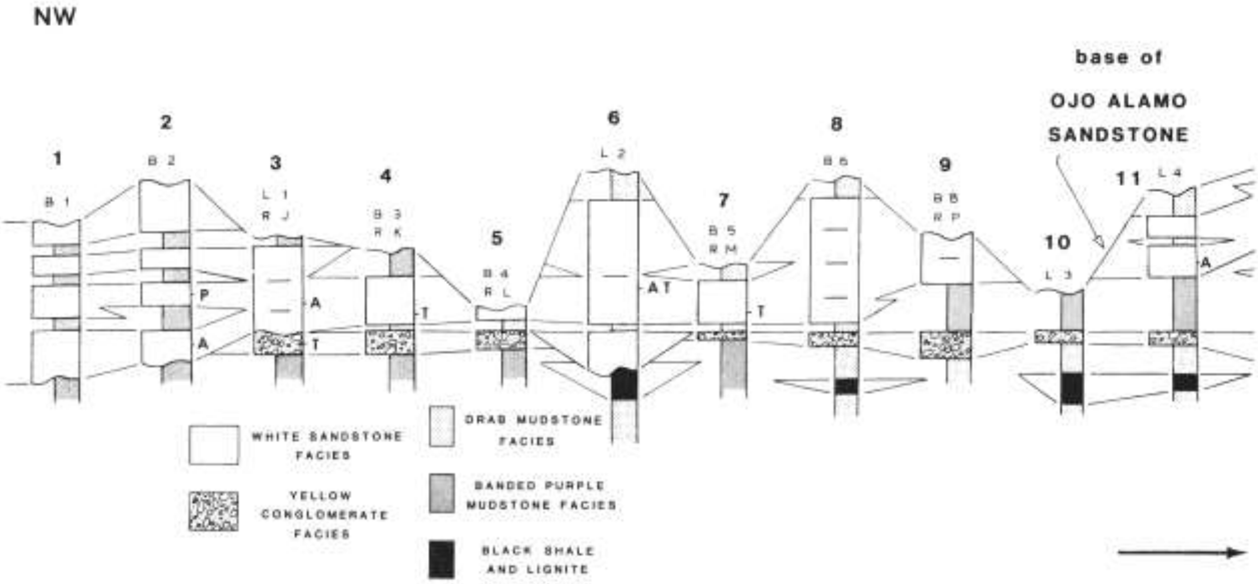


FIGURE 3—Restored cross section through deposits of the Naashoibito Member of the Kirtland Shale in the Hunter Wash–De-Na-Zin Wash area, showing the distribution of the major lithofacies of the Naashoibito. Section locations are shown in Figure 4. **B1, B2,** etc. refer to sections illustrated by Baltz et al. (1966); **RJ, RK,** etc. refer to sections illustrated by Bauer (1916); **L1, L2,** etc. refer to additional sections measured for this study. **A** = stratigraphic position of known *Alamosaurus* specimens, **C** = microvertebrate/coprolite locality, **P** = position of ?*Pentaceratops* specimens, **T** = position of *Torosaurus* specimens (see Appendix).

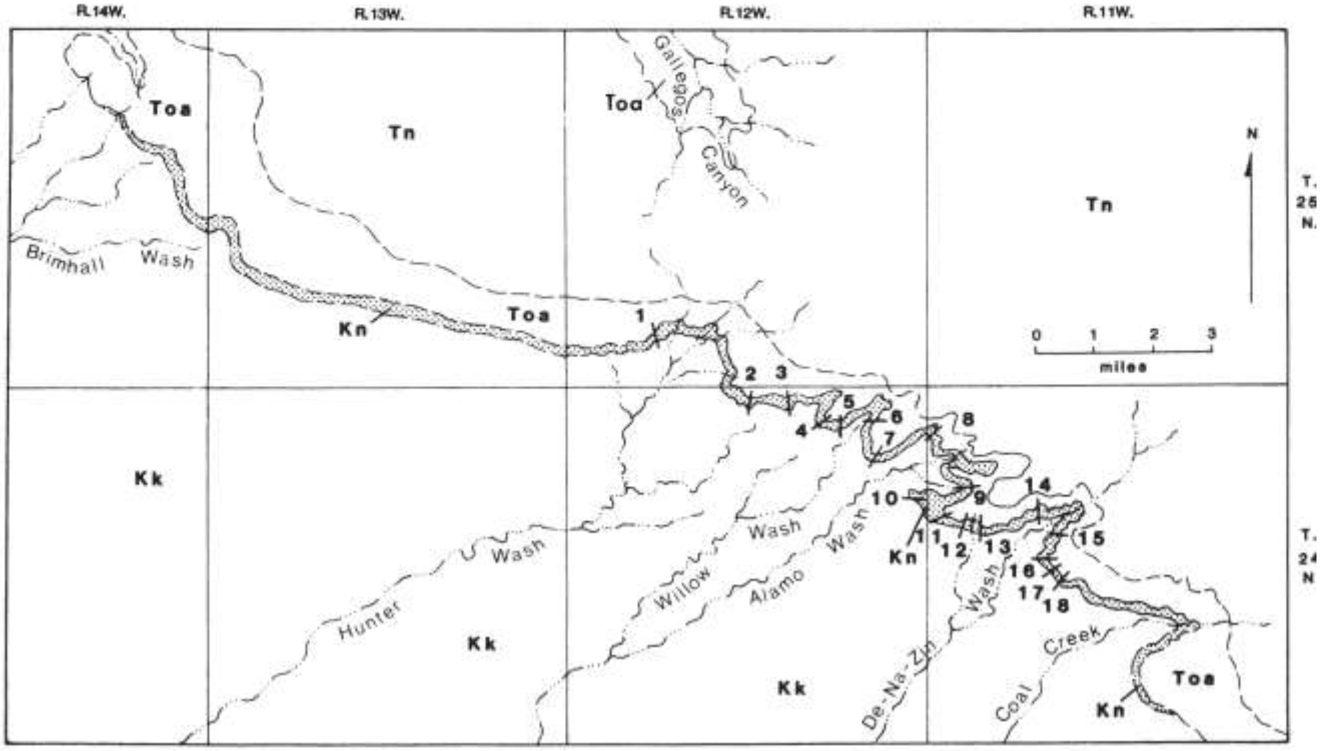
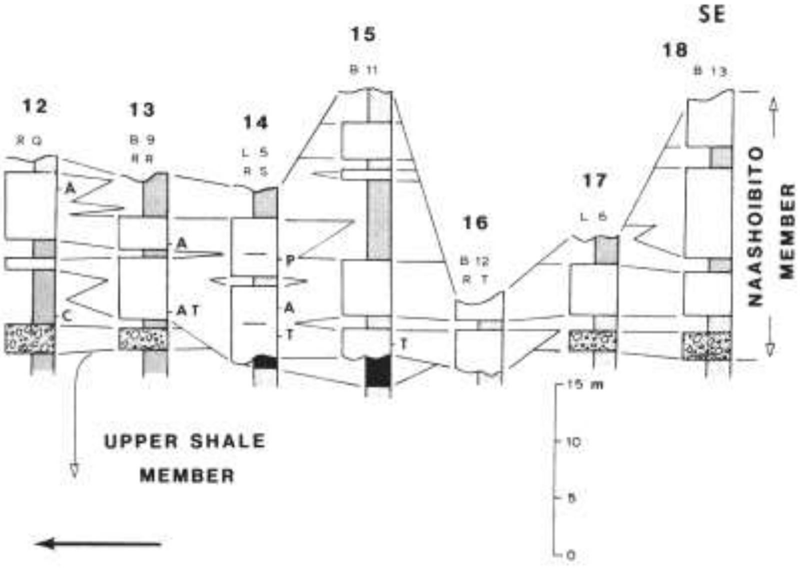


FIGURE 4—Geologic map showing the known and inferred extent of the Naashoibito Member of the Kirtland Shale (**Kn**), and the location of measured sections 1 through 18 shown in Figure 3. **Kk** = Kirtland Shale exclusive of the Naashoibito, **Toa** = Ojo Alamo Sandstone, **Tn** = Nacimiento Formation. Geology adapted from O'Sullivan and Beikman (1963) and Baltz et al. (1966). Geologic contacts are dashed where inferred.



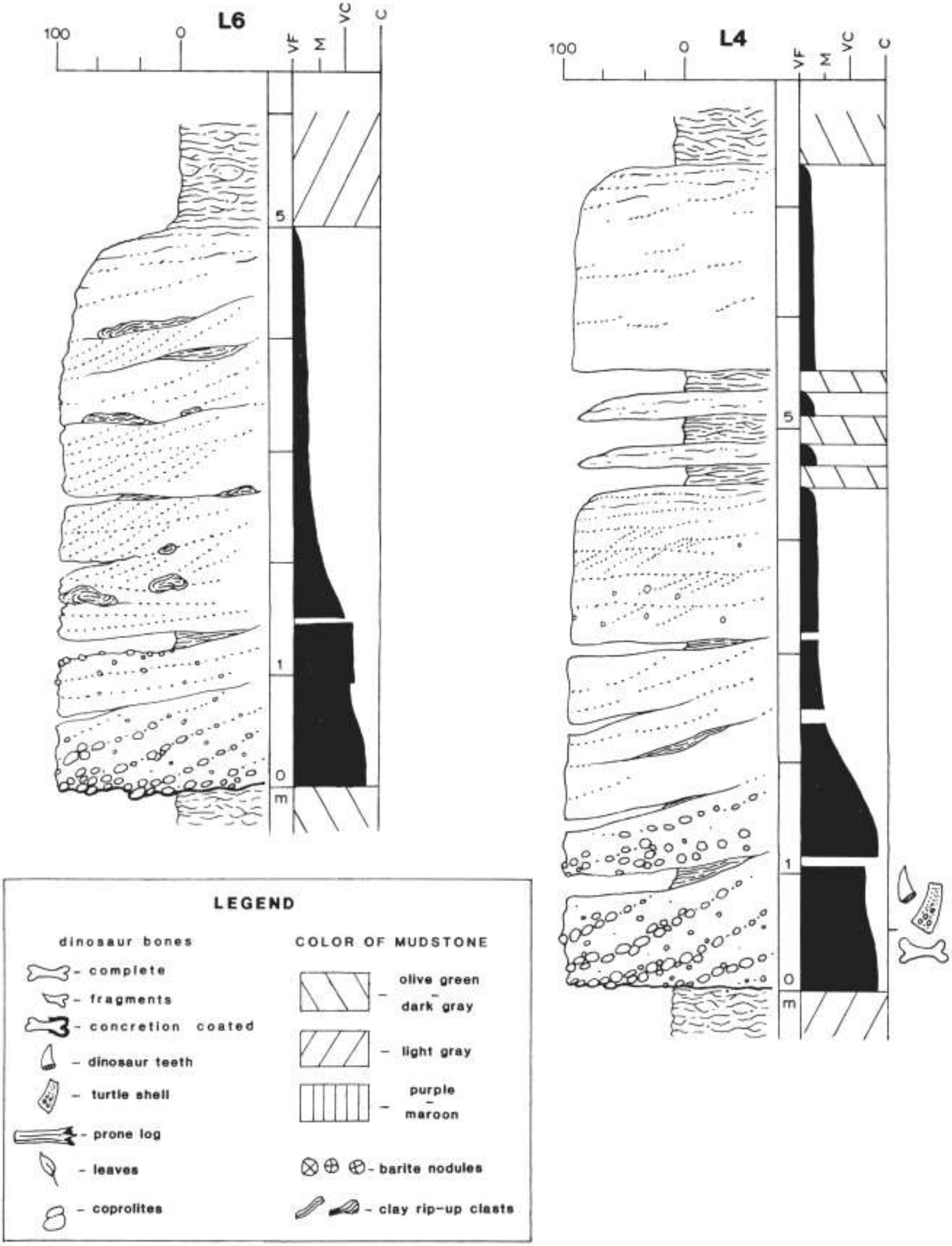


FIGURE 5—Examples of the white-sandstone facies of the Naashoibito Member of the Kirtland Shale. Labels refer to measured sections shown in Fig. 3. Shown on the left side of each measured section is a representation of the sedimentary structures and the percent sand (0–100%). The scale is in meter or half-meter increments, as indicated. On the right side of each section is the modal grain size of sand- and gravel-dominated units (estimated visually; **VF** = very fine sand, **M** = medium sand, **VC** = very coarse sand, **C** = cobble gravel) or the color of mud-dominated units. The position of some fossil localities is given on the right.

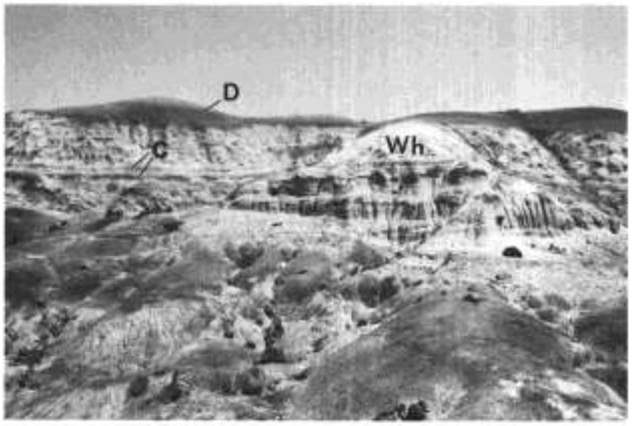


FIGURE 6—White-sandstone facies (**Wh**) and drab-mudstone facies (**D**) of the Naashoibito on the divide between Alamo Wash and De-Na-Zin Wash (section 11 of Fig. 3), showing the basal, gravel-rich, cross-stratified zone and clay-covered accretionary surfaces (**c**). Rod is 1.5 m long.

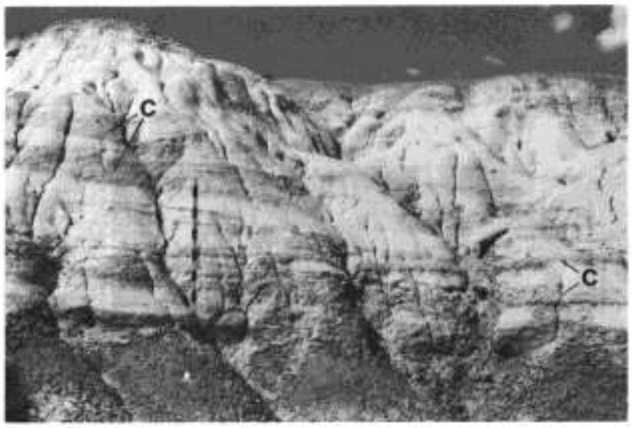


FIGURE 7—White-sandstone facies of the Naashoibito on De-Na-Zin Wash (section 17 of Fig. 3) showing gently sloping, clay-covered, accretionary surfaces (**c**). Rod is 1.5 m long.

shoibito, and much of what these authors include with their "basal conglomeratic sandstone." It is evident at several locations (see below) that the yellow-conglomerate facies of this report has been removed by erosion, and that the incised channels were subsequently filled by sediments of the white-sandstone facies. At these locations the white-sandstone facies rests directly on strata of the upper shale member of the Kirtland, and has thus been previously considered part of the basal conglomerate (Figs. 8, 9).

The white-sandstone facies consists of light gray, poorly indurated, fine- to very coarse-grained immature subarkose (albite—oligoclase) to sublitharenite. Its distinctive white, friable-weathering condition is owing to abundant (about 10 to 20%) interstitial clay. This clay proves under x-ray diffraction to be almost pure smectite. Small pods and encrustations of limonite as well as the large calcite-cemented hematitic cannonball concretions are common throughout this facies.

This facies occurs in units generally about 5 m thick, although in places such units are stacked to form compound sand bodies up to 15 m thick. A sharp, relatively flat erosional surface, locally with deep erosional channels, marks the base of each unit. Limonite-grain coatings are abundant along this surface. The upper surface of each unit is, however, gradational and fines upward into overlying strata, except where truncated by a similar unit. Individual units of the white-sandstone facies are broadly channel-like in geometry, but are very persistent laterally and can be traced along depositional strike for distances up to 1.5 km, where they end by thinning and interfingering with the adjacent banded purple-mudstone facies. No steeply inclined or vertical channel margins occur, except where the white sandstone fills erosional incisions in the yellow-conglomerate facies (Figs. 8, 9). These incised channels descend several meters below the base of the yellow conglomerate and are commonly filled asymmetrically.

Pervasive, gently inclined, clay-covered accretionary surfaces (?epsilon cross strata of Allen, 1965) are the most distinctive internal stratification feature of the white-sandstone facies. These accretionary surfaces exhibit shallow cross-cutting relationships. Large mud lumps (20 to 30 cm in diameter), probably formed by partial destruction of these clay-draped surfaces, are locally incorporated within the sandstone. Smaller, granule to pebble-sized clay galls are abundant on bedding planes. The high intergranular-clay content of this facies may also be, in part, the result of primary deposition of suspended sediment, but other evidence (see below) suggests that the clay originated from early diagenetic alteration of volcanic ash.

Siliceous granule—pebble gravel, similar in mineralogy to that of the yellow-conglomerate facies (see below), occurs as a homogeneous basal lag and along bedding planes in the lower meter of the white-sandstone facies at many places. Sets of low angle (about 10°) cross-stratification, generally 0.5 m thick, are present locally in the lower part of this facies. Large scale (several decimeters thick) trough cross-stratification is present within accretion "wedges" throughout, though it is easily observed only within the cannonball concretions. The scale of the cross-stratification decreases upward, from sets approximately 0.5 m thick in the lower part of a unit to sets 10-20 cm thick in the upper parts. While most of the bounding surfaces between sets are curved, some planar surfaces are also present. In places, horizontally strat-

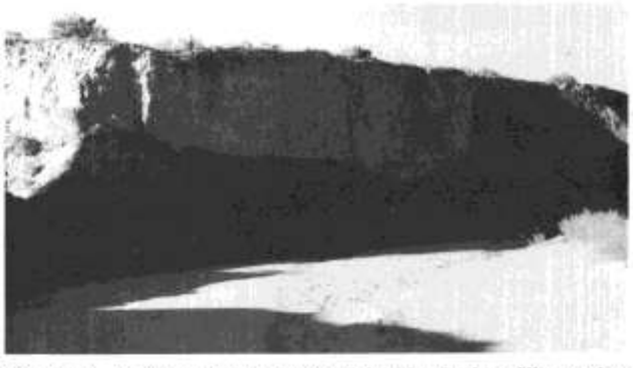


FIGURE 8—White-sandstone facies of the Naashoibito filling a deep channel in carbonaceous shale and lignite of the underlying upper shale member of the Kirtland on Willow Wash (section 6 of Fig. 3). This channel is diagrammed in Fig. 9. Rod is 1.5 m long.

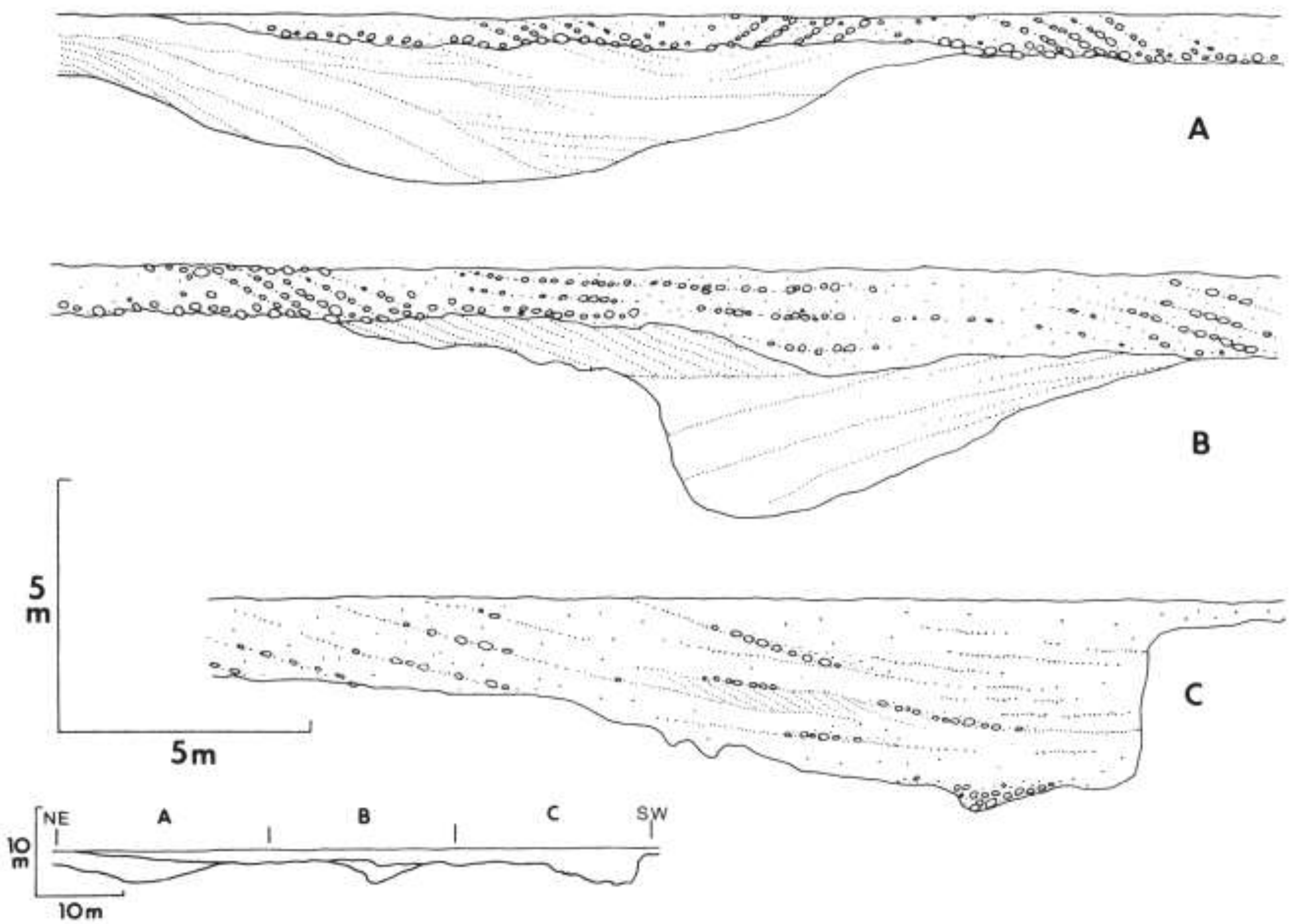


FIGURE 9—A series of superimposed, asymmetrically filled channels in the white-sandstone facies of the Naashoibito in Willow Wash (section 6 of Fig. 3). Channel C is shown in Fig. 8.

ified zones up to 20 cm thick are intercalated with the cross-strata in the upper part of this facies.

Most of the Alamo Wash local fauna (Lehman, 1981) has been collected from the white-sandstone facies of the Naashoibito. Dinosaur limb bones, vertebrae, and skull fragments are relatively common throughout this facies, often encased in the cannonball concretions. Most of the remains are isolated bones or comprise several associated bones. No articulated skeletons have been found. The scattered sauropod limb bones and vertebrae at three localities (Fig. 3) may, however, represent current-winnowed skeletons of single individuals. This may reflect the relative immobility of massive sauropod carcasses as compared to those of other dinosaurs. Fragments of ceratopsian skulls and jaws are the most common large vertebrate fossils. Nodosaurs are represented mostly by abundant osteoderms, carnosaurs mostly by teeth, vertebrae, and phalanges, and hadrosaurs mostly by vertebrae and toothless fragments of dentaries. Most of the skeletal remains in this facies show only mild abrasion and little surficial cracking and erosion; consequently, they must have suffered little transport or weathering prior to burial.

Locally, the conglomeratic lag in the base of the white-sandstone facies contains (in order of abundance) concentrations of fragmentary, heavily abraded turtle and crocodilian bones, carnosaur, sauropod, ceratopsian, and hadrosaur teeth, and gar scales. (See A in section 11 of Fig. 3).

The laterally extensive, and in places multistoried, sand bodies which comprise the white-sandstone facies were probably produced by lateral migration and local superimposed cutting and filling of sinuous stream channels. The great lateral continuity of the sand bodies in this facies, abundance of coarse bedload facies over fine suspended-load facies (banded purple and drab-mudstone facies), and general absence of steep channel margins and mud-filled, abandoned channel deposits suggest that the Naashoibito stream channels had a low sinuosity. Collinson (1978), Leeder (1978), and Kraus (1980), however, suggest that highly meandering streams may also generate laterally extensive sand bodies with little interbedded fine sediment during periods of decreased subsidence and consequent floodplain reworking.

The abundance of shallowly inclined, clay-covered accretionary surfaces in the white-sandstone facies is thought to be typical of point-bar migration in highly sinuous stream channels (Allen, 1965; CoHinson, 1978). Low-sinuosity meandering and sandy braided-stream systems also exhibit lateral migration, however, and it is conceivable that lateral-accretion surfaces may also be present in the alluvium of such streams (Jackson, 1978). Clay-covered accretionary surfaces may be a better reflection of highly fluctuating discharge than they are of the prevailing channel geometry. Likewise, the upward reduction of grain size and scale of sedimentary structures, thought by many to characterize high-sinuosity meandering streams, may also occur in low-sinuosity meandering and sandy braided streams (see Campbell, 1976; Walker and Cant, 1979). The unusual low-angle cross strata in the white-sandstone facies have also been described from both meandering (Kraus, 1980) and braided-stream (Walker and Cant, 1979) deposits. The white-sandstone facies contains a greater proportion of parallel-laminated sand and a lesser amount of planar—tabular cross-stratified sand, than is typically the case in sandy braided-stream alluvium. The Naashoibito stream deposits resemble most closely those of the ash-rich Oligocene Gueydan fluvial system of the Texas coastal plain, described by McBride et al. (1968) and Galloway et al. (1977).

A spectrum of meandering and braided-river types deposit sandy alluvium (Walker and Cant, 1979), and it is not unusual to find deposits such as the white-sandstone facies that exhibit some features of both end members of this spectrum. Baker (1977, 1978) has emphasized how fluvial channels and their sediments adjust to changing climate, sediment load, and discharge; and how, consequently, it is difficult to characterize the channel phases of a large alluvial complex. Sediments of the white-sandstone facies record a time (late Maastrichtian) when uplift, volcanism, and climatic change must have continuously altered the regimen of streams draining terrains in the western interior. Hence, it is best simply to state that the white-sandstone facies resembles most closely deposits of sandy meandering streams and, further, that some evidence suggests these streams had a relatively low sinuosity.

Banded purple-mudstone facies

The striking purple and gray-banded mudstone facies of the Naashoibito is one of its most distinctive features, although it is volumetrically less important than the white-sandstone facies. Similar strata are also present in both the upper shale member of the Kirtland and the contemporaneous McDermott Member of the Animas Formation (see below).

This facies consists predominantly of sandy and silty claystone with some thin lenses and thin sheets of sandstone that is finer-grained, but lithologically identical to and gradational with, the adjacent white-sandstone facies. These thin "apron" sandstones are generally less than 1 m thick, have sharp bases, and gradational tops. Internal stratification is generally absent or obscure, but horizontal lamination is present in places.

The interbedded claystone consists almost entirely of smectite, lacks bedding, and breaks into nodular chunks with slickensides. I have found no identifiable plant remains in these clays, and very little fine macerated plant matter, although some root casts occur. The claystone exhibits well-defined, light-gray and purple or maroon, cyclic color banding. The color bands are tabular in geometry and 20 cm to 2 m in thickness. Gray units are usually much thicker than adjacent purple ones. Individual colored units have a wide aerial extent (up to 1 km) and end either by interfingering with the adjacent thin "apron" sands, by fading out into adjacent color-banded claystone, or by erosional truncation due to scour at the base of the white-sandstone fades. Nowhere have I observed more than three stratigraphically successive gray—purple "couplets."

The bases of the purple-colored units (or tops of underlying gray units) are in many cases very sharply defined and exhibit some faint topographic relief. The tops of the purple units are, however, commonly gradational and intertonguing. The lower parts of some purple units contain thin zones of rubbly, spherical, barite concretions (usually less than 3 cm in diameter) with radiate internal structure. These are often associated with lumpy hematite encrustations.

Both gray- and purple-colored units are poorly fossiliferous. I have observed one locality (C, Fig. 3) in gray claystone that contains numerous small silicified coprolites along with fragments of turtle and crocodilian bones and carnosaur teeth. Bones preserved in purple claystone are often completely or partially encased in a thin, lumpy hematite coating (Fig. 12). The bones and teeth themselves are deeply cracked and have a rotted appearance, suggesting prolonged weathering prior to burial and perhaps chemical dissolution following burial. Several upright tree stumps found in purple claystone are surrounded by hematite encrustation, while what was woody material inside is reduced to powder.

The banded purple-mudstone facies of the Naashoibito represents floodplain sediments deposited in overbank environments adjacent to the stream channels of the white-sandstone facies. The variegated, banded appearance of these sediments is a result of repeated periods of soil formation during aggradation of the floodplain. The Naashoibito paleosols are well differentiated into a pale-gray leached (albic) A horizon and a purple iron-enriched (spodic) B horizon. The purple, rather than the more typical red or orange, coloration of the B horizon may reflect diagenetic coarsening of disseminated hematite crystals which originated by recrystallization of soil sesquioxides (see McBride, 1974; Folk, 1976). No organic (0) horizons are preserved.

Such well-differentiated peds with little humified organic material at the surface of the A horizon and abundant ferric-oxide stains and crusts in the B horizon are characteristic of modern podzols of woodlands and forests, and indicate well-drained oxidizing and acidic soil conditions subject to frequent dry periods (Retallack, 1981). The great thickness of the A horizons (up to 2 m in some cases) relative to the associated B horizons (as thin as 20 cm) suggests active cumulization between periods of soil formation.

Although plant remains have not been found in the Naashoibito paleosols owing to the oxidizing soil conditions, the absence of original bedding, nodular structure, and pervasive slickensides in the clay suggest they supported a well-established vegetation. Palynological investigations (Dickinson et al., 1968; Baltz et al., 1966) have revealed an abundance of conifer pollen in the upper part of the Kirtland Shale

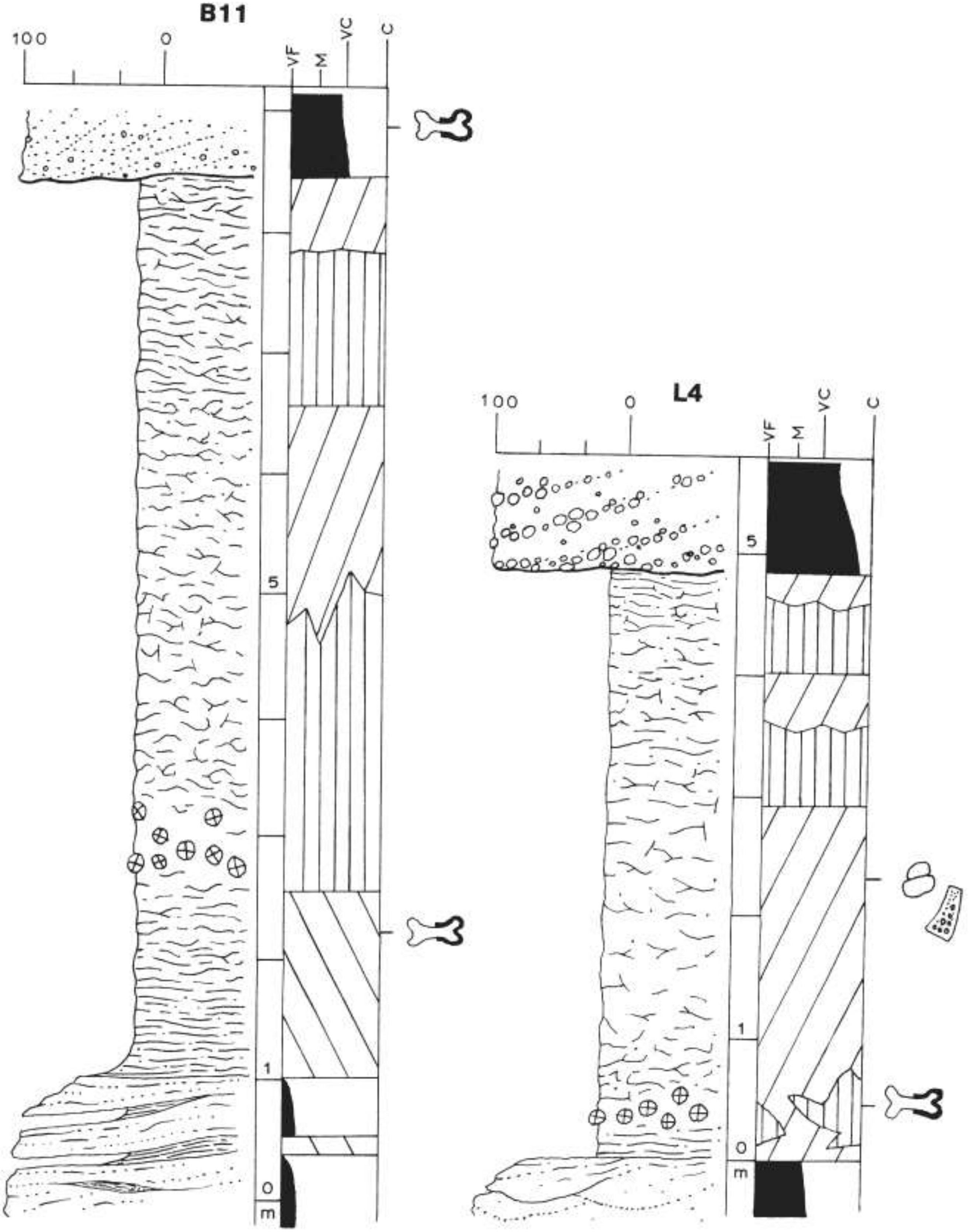


FIGURE 10—Examples of the banded purple-mudstone facies of the Naashoibito. Labels refer to measured sections shown in Fig. 3. Legend for symbols is given in Fig. 5.

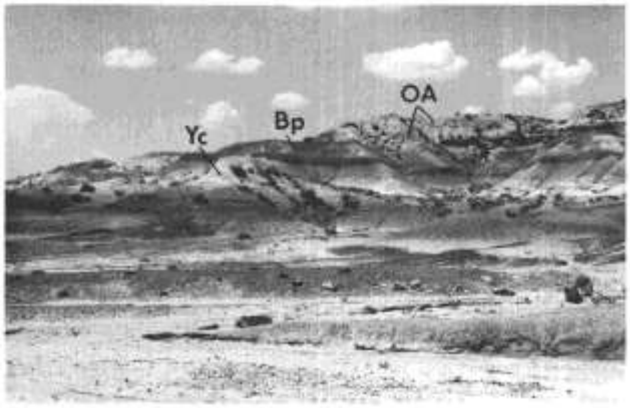


FIGURE 11—Banded purple-mudstone facies of the Naashoibito on Alamo Wash (section 10 of Fig. 3). **BP** = Banded purple-mudstone facies, **YC** = yellow-conglomerate facies, **Ku** = Upper Shale Member, **OA** = Ojo Alamo Sandstone.

compared to underlying strata. Conifers dominated inland floodplain vegetation throughout North America during much of the Cretaceous (Retallack and Dilcher, 1981). It seems likely that the Naashoibito paleosols supported coniferous forests, although conifer pollen can be widely distributed into areas where conifers are absent. The thin sandstone lenses and sheets interbedded with the purple and gray paleosol couplets represent levee and crevasse splay deposits formed adjacent to channels during flooding.

Although I have found no discrete tuff beds in this facies, the very high smectite content of the clay and the abundant volcanic clasts in the white-sandstone facies suggest that the clay was derived at least in part from the devitrification of volcanic ash. The barite nodules may also find explanation in this manner.

Barium is common as a trace element in many soils. It is readily hydrated but relatively immobile, is not fixed by clay minerals, and tends to increase in concentration below the soil surface and accumulate in the subsoil (Bohn et al., 1979; Aubert and Pinta, 1977; Chattopadhyay and Jervis, 1974). Volcanic ash could well have been the source of barium at the soil surface in the Naashoibito paleosols (see Dethier et al., 1981). Leached, hydrated Ba ++ ions could have reacted with SO; in the soil solution (derived from the dissolution of gypsum common in the underlying upper shale member) to produce barite. Such a reaction is at least tenable thermodynamically. The Naashoibito barite nodules may thus be pedogenic in nature, although proof of this is wanting. The form and mode of occurrence of the barite nodules is similar to that of other soil glaebules. To my knowledge, such accumulations are only rarely described from modern soils (Beattie and Haldane, 1958).

Yellow-conglomerate facies

The term "yellow conglomerate" is used in a restricted sense here, to include only the thin "bench-forming" part of the basal conglomeratic sandstone of the Naashoibito Member as described by Baltz et al. (1966). These bench-forming segments are lithologically and sedimentologically distinct from the remainder of the unit delineated as "lower conglomerate" by Baltz et al. (1966).

The yellow-conglomerate facies consists predominantly of submature, gray, medium- to coarse-grained conglomeratic litharenite. This facies is in most places 2 m or less in thickness and rests on an irregular, undulatory, though not deeply channeled, erosional surface. This lower surface is marked in most places by a prominent yellow—orange limonitic zone in the base of the yellow conglomerate and in the top 0.5 m of sandy silts and clays of the underlying upper shale member of the Kirtland. This probably represents fairly recent limonite deposition by ground water moving through this zone of differential porosity. The upper bounding surface of the yellow conglomerate is abrupt, though conformable with overlying facies. The yellow-conglomerate facies is sheetlike in geometry and persists laterally the full extent of most outcrops where it is exposed. However, in at least two locations (Fig. 3) this facies pinches out for short distances (several meters) into surrounding strata. At these places, the yellow conglomerate is apparently truncated by the white-sandstone facies (see above). Along some stretches, the yellow-conglomerate facies thins to less than 1 m of structureless pebbly sand (Fig. 14), but it is always identifiable and continuous for at least 15

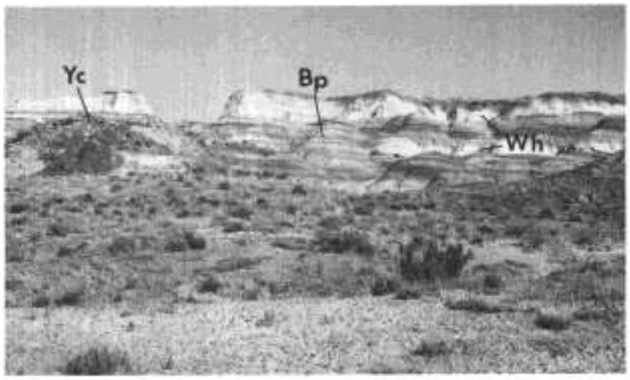


FIGURE 13—Exposure along the north side of De-Na-Zin Wash (sections 13 and 14 of Fig. 3) where yellow-conglomerate facies (**YC**) is replaced laterally by white-sandstone facies (**Wh**). **BP** = Banded purple-mudstone facies.

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FIGURE 14—"Condensed" section of the yellow-conglomerate facies (**YC**) on the divide between Alamo Wash and De-Na-Zin Wash (section 11 of Fig. 3). Such sections developed by erosional deflation on interfluves.

km of exposure in the Hunter Wash–De-Na-Zin Wash confluence.

Internally, the yellow-conglomerate facies exhibits abundant primary sedimentary structures at many outcrops (Figs. 15-17). A crude fining-upward trend is apparent in most sections measured. The absence of any consistent vertical sequence of sedimentary structures is striking. At several locations, however, a lower zone of horizontally stratified gravel and gravelly sand is overlain by tabular, trough, and rippled cross-stratified sand. The gravel is predominantly pebble-sized, well rounded, equidimensional gray chert, quartzite, and vein quartz, petrified wood, nodules of silicified Paleozoic limestone, and silicic and intermediate volcanic rocks (see Reeside, 1924; Baltz et al., 1966). Sandstone cobbles up to 20 cm in diameter also occur.

Baltz et al. (1966) reported that pebbles in the overlying Ojo Alamo Sandstone were of the same lithology as those of the Naashoibito. Powell (1972), however, found that gravel in the Ojo Alamo has a higher ratio of siliceous to volcanic pebbles than that of the Naashoibito. At two locations (NW 1/4 NW 1/4 Sec. 2 and SW 1/4 SE 1/4 Sec. 12, T. 24 N., R. 12 W.) similar siliceous pebbles occur in sandstones of the upper shale member 14 m and 7 m, respectively, below the base of the Naashoibito in the Hunter Wash–De-Na-Zin Wash area. The upper shale member of the Kirtland in the northwest part of the basin also contains such pebbles (see Reeside, 1924; Barnes et al., 1954; O'Sullivan et al., 1972). Gravel in the white-sandstone facies is similar lithologically to that of the yellow-conglomerate facies, though it is dominantly of granule to pebble size in the white-sandstone facies, rather than pebble to cobble size. The white-sandstone facies also contains a greater proportion of volcanic pebbles than the yellow conglomerate.

Gravel in the Naashoibito (both white-sandstone and yellow-conglomerate facies) is dominated by large pebbles and cobbles of chert, quartzite, and vein quartz. Volcanic-rock fragments are almost wholly of granule to small pebble size, are more strongly weathered, and in many cases are partly altered to smectite. At least three distinct lithologies are present among the volcanic rock fragments. Most abundant is a porphyritic andesite with drab-gray–green aphanitic ground-mass and euhedral plagioclase phenocrysts. Most of the phenocrysts appear altered and have deteriorated cores. Also common is porphyritic dacite with white to light-gray aphanitic groundmass and phenocrysts of plagioclase, quartz, and biotite. Least abundant is porphyritic rhyolite with dark-red–brown ground-mass and quartz and potassium-feldspar phenocrysts. The common occurrence of clear euhedral bipyramidal quartz crystals and biotite flakes in the coarse-sand size fraction also demonstrates a volcanic source for much of this sediment. The pebbles of silicified fossiliferous Paleozoic limestone noted by Baltz et al. (1966) are likewise common. I have observed spiriferid and productid brachiopods, fenestrate bryozoans, and crinoid columnals in such pebbles, some of which suggest derivation from Pennsylvanian strata.

The cross-stratified sands in the yellow-conglomerate facies are marked by numerous reactivation surfaces, silt drapes, and soft-sediment deformation. The silt drapes have been torn up in places and incorporated as clasts in the sand. Some bounding surfaces between adjacent sets of cross strata exhibit "pebble armoring." Primary current lineation is present in some horizontally stratified sands. Most of the soft-sediment deformation is contorted forset lamination—overturned in a down-current direction.

Fossils are rare in the yellow-conglomerate facies. In places, leaf fragments are concentrated on bedding planes. Several small branches and trunks were observed, but no large logs, such as occur in the overlying Ojo Alamo Sandstone, were found. Vertebrate remains are isolated, fragmentary, and moderately to heavily abraded (see Shipman, 1981) indeterminate dinosaur limb-bone fragments and vertebrae. Nodosaur osteoderms are notably abundant. These remains commonly show surficial cracking and rotted cancellous parts, indicating prolonged weathering before burial (Fig. 18). No articulated or even associated skeletal remains have been found in this facies. The apparent preferred occurrence of vertebrae and osteoderms suggests that most of the remains were transported prior to burial.

The sheet-like yellow-conglomerate facies is unusual in its thinness and great lateral extent. The geometry and stratification of this facies suggest that it was deposited by a sand-dominant braided-stream system (see Rust, 1978). The low ratio of gravel to sand (<10%) and fining-upward sequence in this facies resembles that of a single cycle of "South Saskatchewan type" braided-stream deposit (Miall, 1978); however, the yellow-conglomerate facies is much thinner (see Walker and Cant, 1979). The striking lateral variation in the sequence of sedimentary structures probably reflects alternating in-channel and adjacent bar or "sand flat" deposition. Sequences of crudely horizontally stratified gravel and gravelly sand (high-flow-stage deposits) overlain by tabular and trough cross-stratified sand (low-flow-stage deposits) may represent deposits formed by the development of channel bars (Fig. 15). Sequences of massive gravel and trough cross-stratified gravelly sand represent fill of active channels (Fig. 16), whereas sequences with thin gravel lags overlain by tabular cross-stratified and ripple cross-laminated sand represent fill of abandoned (slough) channels (Fig. 17). The abundance of

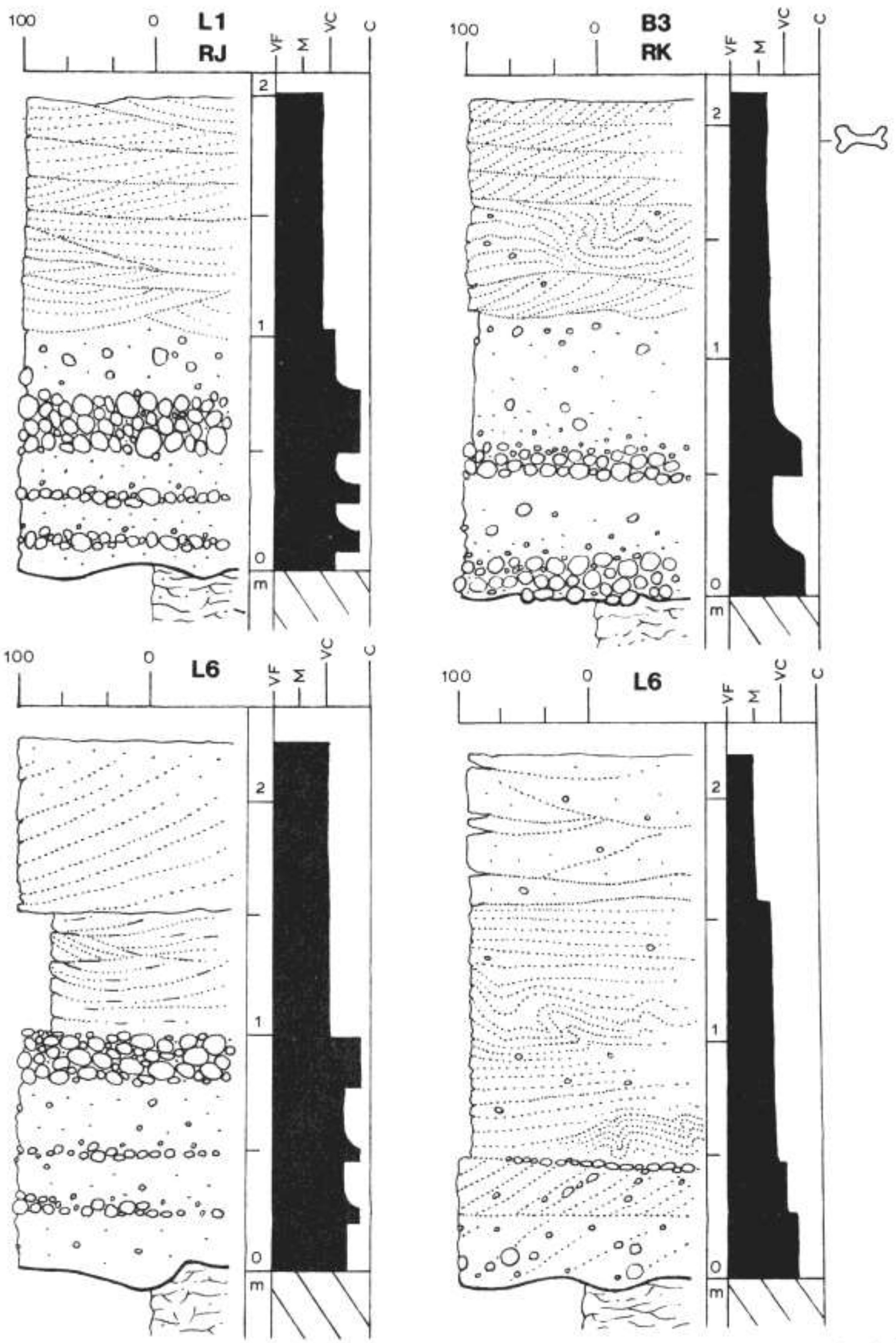

FIGURE 15—Examples of the yellow-conglomerate facies of the Naashoibito. These examples illustrate deposition on braided-channel bars. Labels refer to measured sections shown in Fig. 3. Legend for symbols is given in Fig. 5.

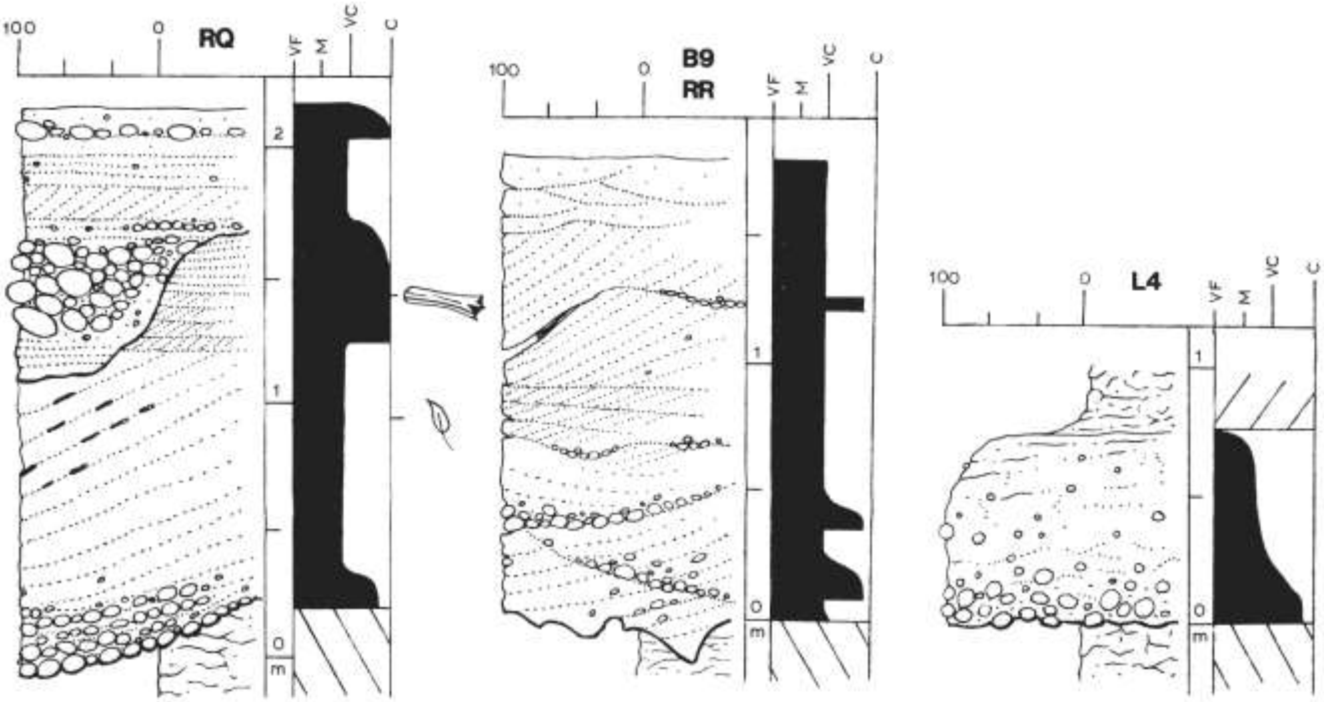

FIGURE 16—Examples of the yellow-conglomerate facies of the Naashoibito. These examples (**RQ** and **B9 RR**) illustrate deposition in active braided channels, and (**L4**) typical "condensed" sections developed by erosional deflation. Labels refer to measured sections shown in Fig. 3. Legend for symbols is given in Fig. 5.

reactivation surfaces, silt drapes, and pebble armoring in slough-channel fills are evidence for a variable discharge during deposition of the yellow-conglomerate facies.

Drab-mudstone facies

The drab-mudstone facies is volumetrically the least important of the four major lithofacies. It consists of olive-green, brown, and dark-gray silty claystone with thin interbeds of friable sandstone identical to that of the white-sandstone facies. The claystone is poorly bedded and contains some carbonaceous plant debris, but no vertebrate fossils have been found. Unlike the banded purple-mudstone facies, there is no consistent alternation of color bands in the drab mudstone. This facies occurs primarily as thin lenses and tongues within the white-sandstone facies, and in many places as a thick persistent unit above the white-sandstone facies. In areas where a significant thickness of the Naashoibito is preserved beneath the Ojo Alamo, the drab-mudstone facies is stratigraphically the highest facies represented (Fig. 14).

These deposits, like those of the banded purple-mudstone facies, probably represent slackwater deposits in channels and floodbasin deposits. McBride (1974) suggested that drab-green mudstones, similar to these, form when reducing water in overlying channel sandstones percolates through and bleaches originally purple beds. However, both banded purple and drab-green-mudstone facies occur with equal frequency beneath channel sandstones in the Naashoibito, and this process cannot completely account for the formation of the drab-colored beds. Bown and Kraus (1981) attribute drab coloration in similar mudstones to the formation of poorly differentiated soils (entisols) in areas undergoing rapid sediment accumulation. Waterlogged soil conditions are also indicated (Retallack, 1981).

Unlike the banded purple-mudstone facies, the drab-mudstone facies probably accumulated in poorly oxygenated, water-saturated, reducing environments not subject to strong soil-forming processes, and not heavily forested. These conditions developed in areas closer to channel environments than those under which the purple-mudstone facies accumulated.

Depositional history

The four major lithofacies of the Naashoibito record sedimentation in the varied environments of a large fluvial depositional system. The excellent exposures of these deposits allow a detailed history of their accumulation and an environmental reconstruction to be presented.

As an adjunct to his work on the Ojo Alamo, Powell (1972) reported a general southerly to southwesterly transport direction for Naashoibito sediments, with an average of S 10° W to S 40° W for the dip azimuth of cross-stratification. It is uncertain which of Powell's measurements came from the more restricted limits of the Naashoibito adopted here. I have, however, taken a limited number of paleocurrent measurements from the yellow-conglomerate and white-sandstone facies of the Naashoibito, and these confirm Powell's general observation. The Naashoibito outcrop from Hunter Wash to De-Na-Zin Wash runs

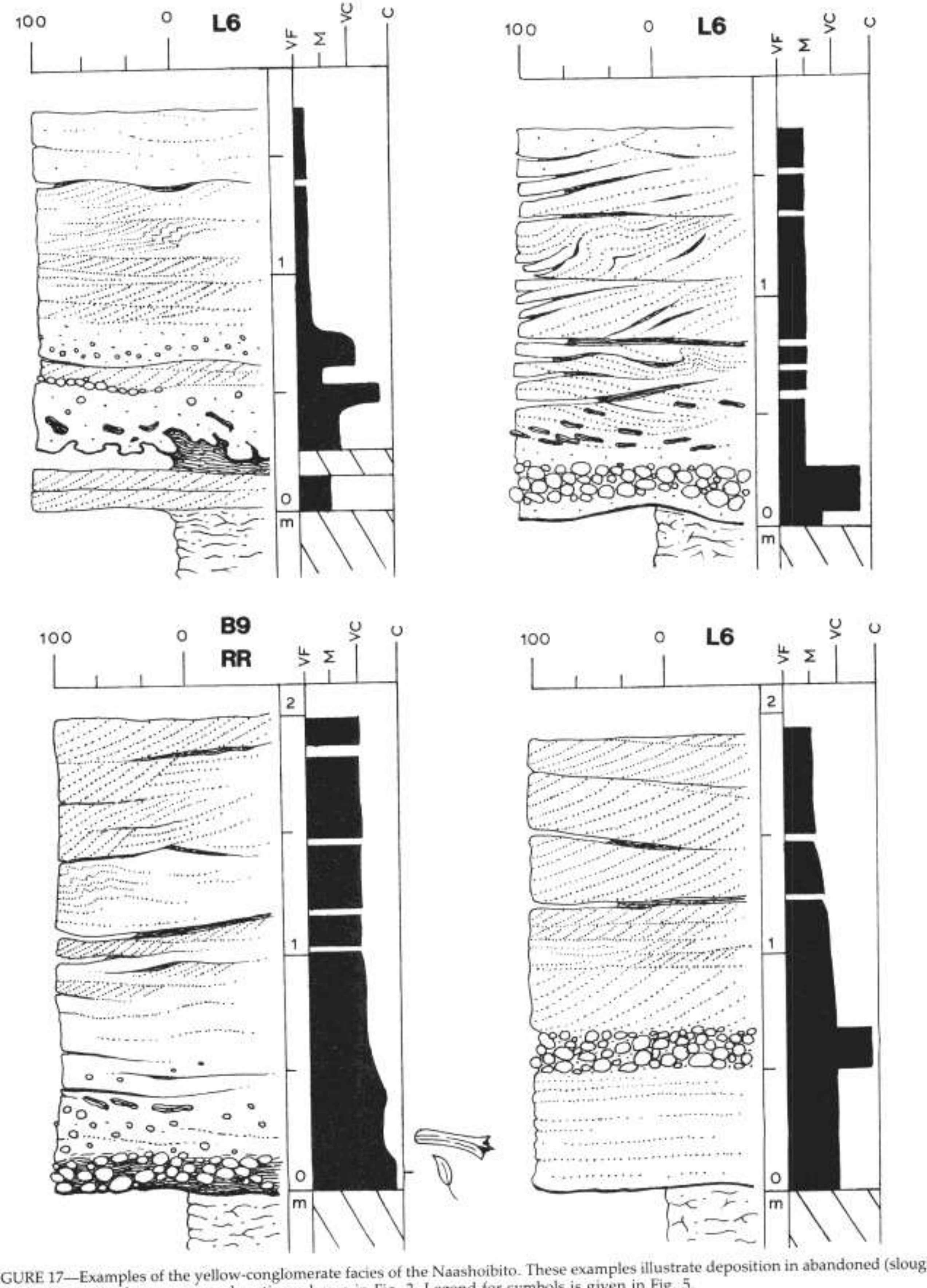

FIGURE 17—Examples of the yellow-conglomerate facies of the Naashoibito. These examples illustrate deposition in abandoned (slough) channels. Labels refer to measured sections shown in Fig. 3. Legend for symbols is given in Fig. 5.

FIGURE 18—Ceratopsian caudal vertebrae from the yellow-conglomerate facies, showing the cracked and rotted condition common in bones found in this facies.

northwest to southeast, and thus exposes the Naashoibito roughly perpendicular to its depositional dip. The restored line of section shown here (Fig. 3) thus constitutes a strike section, with the paleoflow direction toward the viewer.

Major channels in the Naashoibito alluvial system apparently occupied the sites of pre-existing channels or topographic lows in the upper shale member surface. The major axes of the channel systems are marked by: 1) truncation of the yellow-conglomerate facies, 2) deeply incised channels filled by the white-sandstone facies, and 3) overlying thick accumulations of the white-sandstone facies (see Fig. 3). These axes commonly occur over, and erode into, lenticular carbonaceous shale and lignite deposits of the upper shale member that probably represent filled flood-basin swamps. The lignite lenses pinch out laterally into drab mudstones, which in turn grade into banded purple and gray mudstone like that of the Naashoibito. Consequently, oxidation of the sediment, soil differentiation, and forestation during upper shale member time was probably controlled more by proximity to drainage than by any substantial topographic relief.

Deposition of the Naashoibito began when a thin sheet of coarse braided-stream alluvium (yellow-conglomerate facies) spread southward over the upper shale member surface (Fig. 19, A). The original dimensions of this sheet are unknown because the entire Naashoibito is truncated by erosion at the base of the Ojo Alamo, both northwest and southeast of the Hunter Wash—De-Na-Zin Wash area (see below). The thin, enigmatic deposit of the yellow-conglomerate facies records an initial short-lived episode of uplift and denudation in the source terrain, which spawned and fed sediment-choked streams flowing south. While the base of this gravelly sand sheet is erosional, this probably has not resulted in a substantial unconformity.

Following this uplift, a period of tectonic quiescence ensued, during which streams incised deep channels into and through the thin sheet of coarse alluvium, stranding it as a terrace (Fig. 19, B). Parts of this terrace underwent more erosion than others, and in places the coarse alluvial cover was deflated to a thin veneer of unstructured gravelly sand.

Later, as the newly formed San Juan Basin began to subside, the streams aggraded, filling the incised channels (Fig. 19, C). These mixed-load streams had a sinuous channel pattern and transported finer sediment rich in volcanic debris derived from the active San Juan volcanic field (white-sandstone facies). As the channels aggraded, overbank deposits began acccumulating on, and burying, the terrace of coarse alluvium. These muddy overbank deposits were well drained and underwent successive periods of soil formation, supporting generations of coniferous forest (banded purple-mudstone facies). The thickest accumulations of this facies overlie similar deposits in the

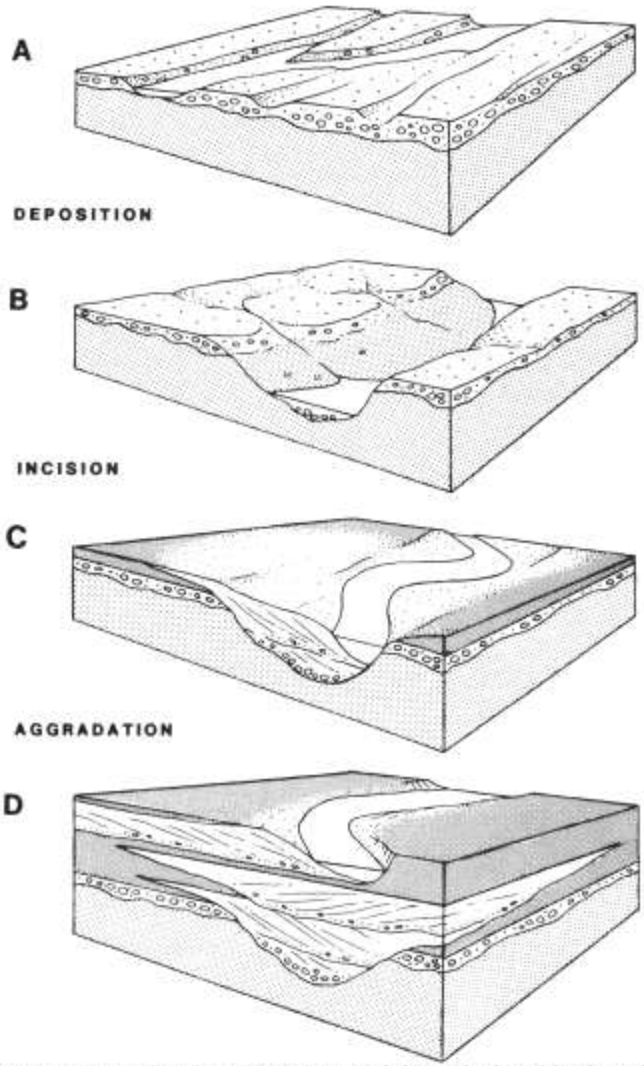

FIGURE 19—Model for deposition of the Naashoibito Member of the Kirtland Shale. Initial deposition of the yellow-conglomerate facies (**A**) was followed by incision of channels and deflation of the yellow conglomerate (**B**). The incised channels were later filled with the white-sandstone facies (**C**); as the floodplain aggraded, the banded purple and drab-mudstone facies accumulated (**D**).

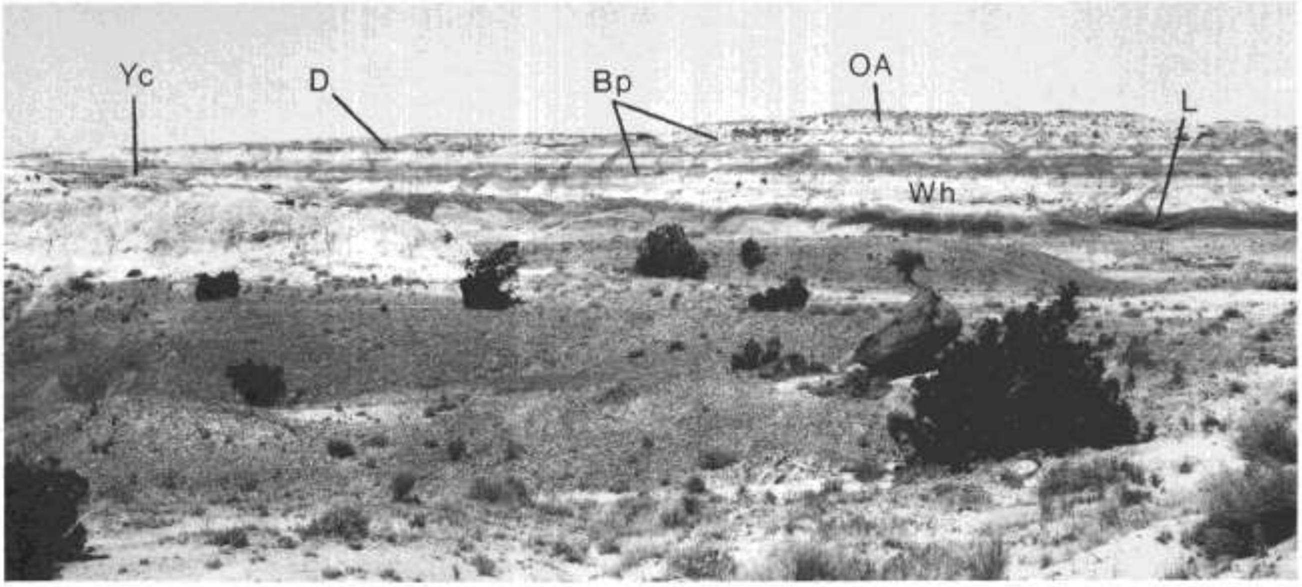

FIGURE 20—Exposure on the north side of De-Na-Zin Wash showing the relationship between the yellow-conglomerate (**YC**), white-sandstone (**Wh**), banded purple-mudstone (**BP**), and drab-mudstone (**D**) facies of the Naashoibito. Note descent of the white-sandstone facies toward right, and erosional truncation of lignite (**L**) in upper shale member of the Kirtland. **OA** = Ojo Alamo Sandstone.

upper shale member, suggesting that the forested interfluves had remained somewhat stable through time. Muddy sediments which accumulated in slackwater and overbank areas closer to the stream channels remained waterlogged and did not experience soil formation or support a long-standing vegetation (drab-mudstone facies). Well-differentiated soils in the banded purple-mudstone facies, reactivation surfaces and silt drapes in the yellow-conglomerate facies, and clay-covered accretionary surfaces in the white-sandstone facies reflect a fluctuating hydrological regime and perhaps a seasonal climate during deposition of the Naashoibito.

The basin continued to subside, and the streams that had completely filled the incised channels became free to migrate across their floodplains (Fig. 19, D). Laterally extensive channel and overbank sediments accumulated as subsidence kept pace with channel migration. The relationships between the major lithofacies of the Naashoibito are particularly accessible and well illustrated in the exposures along the north side of De-Na-Zin Wash (Fig. 20).

Fauna of the Naashoibito

The vertebrate fauna of the Naashoibito is known as the Alamo Wash local fauna (see Lehman, 1981). Collections of this fauna have been described by Brown (1910), Hay (1908, 1910), Gilmore (1916, 1919, 1922), Wiman (1931, 1933), Mateer (1976), and Kues et al. (1980). The fauna has recently been redescribed with additions and emendations to conform to present usage (Lehman, 1981). The faunal list is reproduced here with several additions and corrections:

Class Osteichthyes
  Order Lepisosteiformes
    Family Lepisosteidae
    Lepisosteus sp.
      Order Cypriniformes
    Family Cyprinidae gen. et
      sp. indet.

Class Reptilia
  Order Testudines Family
    Baenidae *Thescelus*
    insiliens Neurankylus
    eximius "Baena"
    nodosa Compsemys
    sp.
    Family Trionychidae
      Aspideretes vorax
      Aspideretes fontanus
      Aspideretes austerus
    Family Dermatemydidae
      Adocus vigoratus
      Basilemys nobilis
      Hoplochelys cf. *bicarinata*
  Order Saurischia
    Family Tyrannosauridae
      ?Albertosaurus sp.
    Family Saurornithoididae
      gen. et sp. indet.
      Family Titanosauridae
      Alamosaurus sanjuanensis
  Order Ornithischia
    Family Hadrosauridae
      Kritosaurus navajovius
      Parasaurolophus tubicen
    Family Ceratopsidae
      ?Pentaceratops sp.
      Torosaurus cf. *utahensis*
      Family Nodosauridae
      ?Panoplosaurus sp.

Order Crocodylia
  Family Crocodylidae
    crocodyline gen. et sp. indet.
    alligatorine gen. et sp. indet.
    Family Goniopholididae
    Goniopholis sp.

Class Mammalia
  Order Multituberculata
    Family ?Cimolomyidae
    Essonodon cf. *browni*
    Order Marsupialia
    Family Didelphidae
      Alphadon sp.

The metatherian *Alphadon* sp. has recently been reported by Lindsay et al. (1981), and the multituberculate *Essonodon browni* reported here is based on a single M, (UNM FKK-020) tentatively identified by W. A. Clemens (pers. comm. 1981). The unusual small scapula figured by Lehman (1981, fig. 9.9) and identified as a ?hypsilophodont is in fact probably a juvenile sauropod scapula (P. M. Gallon, pers. comm. 1982). The indeterminate crocodyline and alligatorine represent revised identification of material described earlier by Lehman (1981).

Virtually the entire fauna has been collected from the white-sandstone facies of the Naashoibito. Assemblages of all transport groups (or "Voorhies' Groups" sensu Behrensmeyer, 1975) are known from this facies. Partly associated lag accumulations of sauropod appendicular bones and vertebrae and of fragmentary ceratopsian skulls, as well as transported, current-accumulated remains of turtles and crocodilians mixed with various dinosaur teeth and nodosaur osteoderms are present. Bones in the yellow-conglomerate facies, however, suffered greatly from weathering and abrasion prior to burial, and represent mostly transported elements. The few bones preserved in the banded purple-mudstone facies also suffered greatly from weathering and soil-forming processes.

The dominant large terrestrial vertebrates of the Alamo Wash local fauna are the sauropod dinosaur *Alamosaurus* and the ceratopsian *Torosaurus*. Existing collections do not accurately reflect this because most of the remains of these animals are fragmentary and poorly preserved, and have often been passed over by collectors or simply noted in the field. This frequency may reflect a real abundance, or it may be owing to the fact that these animals frequented stream-channel environments where the white-sandstone facies accumulated. Bones of hadrosaurs, nodosaurs, carnosaurs, and deinonychosaurs are encountered less frequently, but are similarly preserved.

Stream-channel environments of the Naashoibito supported a diverse fauna of turtles and crocodilians, but, unlike in-channel environments of the underlying parts of the Kirtland Shale, there are no sharks, rays, sturgeons, bowfin fishes, or unionid bivalves and a dearth of gars. Presumably, this reflects the inland depositional setting of the Naashoibito (Lehman, 1981; Lucas, 1981). The generally disarticulated and widely scattered condition of most of the large terrestrial-vertebrate remains, compared with those of the lower part of the Kirtland, is probably a result of scavenging and transport, but it may also be a reflection of stream velocities in Naashoibito channels that were higher than those which deposited the lower Kirtland. The Alamo Wash local fauna is considered to be late Maastrichtian (Lancian) in age (Lehman, 1981).

Correlation of the Naashoibito Member

Baltz et al. (1966) mapped strata on the east fork of Coal Creek, south of the Hunter Wash—De-Na-Zin Wash area, as Naashoibito. However, these deposits do not resemble those of the Naashoibito in its type area, and consist entirely of drab-green and gray mudstone and small lenses of white sandstone. Also, unlike deposits of the Naashoibito, these sediments contain numerous silicified logs and stumps in situ, and abundant hadrosaur remains. Lithologically and paleontologically, the deposits below the Ojo Alamo Sandstone on the east fork of Coal Creek are like those of the upper shale member of the Kirtland in the Hunter Wash—De-Na-Zin Wash area and in Ah-She-Sle-Pah Wash. The sandstone with clay galls on Coal Creek that Baltz et al. (1966) correlated with the basal conglomerate of the Naashoibito may be part of the thinned Farmington Sandstone Member of the Kirtland Shale, which had risen stratigraphically to about 30 m below the Ojo Alamo on De-Na-Zin Wash. Thus, somewhere on the covered divide between De-NaZin Wash and the east fork of Coal Creek, the Naashoibito Member is probably truncated beneath the Ojo Alamo (Fig. 4). The Farmington Sandstone Member continues to rise stratigraphically, and on the east fork of Coal Creek only 9 m of upper shale member remain between it and the base of the Ojo Alamo.

The Naashoibito Member is not present farther south nor on the eastern side of the San Juan Basin. Powell (1972) suggested that the Naashoibito was a continuous unit throughout the southern and eastern San Juan Basin; however, the distinctive lithofacies and vertebrate fauna of the Naashoibito are unknown in these areas. At the heads of Ah-She-Sle-Pah and Betonnie—Tsosie Arroyos, banded purple mudstone and white sandstone (lacking siliceous pebbles, but similar to that of the Naashoibito) occur below the Ojo Alamo. But, as noted above, the upper shale member of the Kirtland also exhibits these lithologies in places below the Naashoibito. There is also no basal conglomeratic sandstone in these areas. I correlate strata at the heads of these arroyos with the upper shale member.

North of the Hunter Wash—De-Na-Zin Wash confluence, the Naashoibito is erosionally thinned and eventually truncated beneath the Ojo Alamo along the north side of Brimhall Wash (see Powell, 1972: 23). Continuing north, on the Navajo Indian Reser-

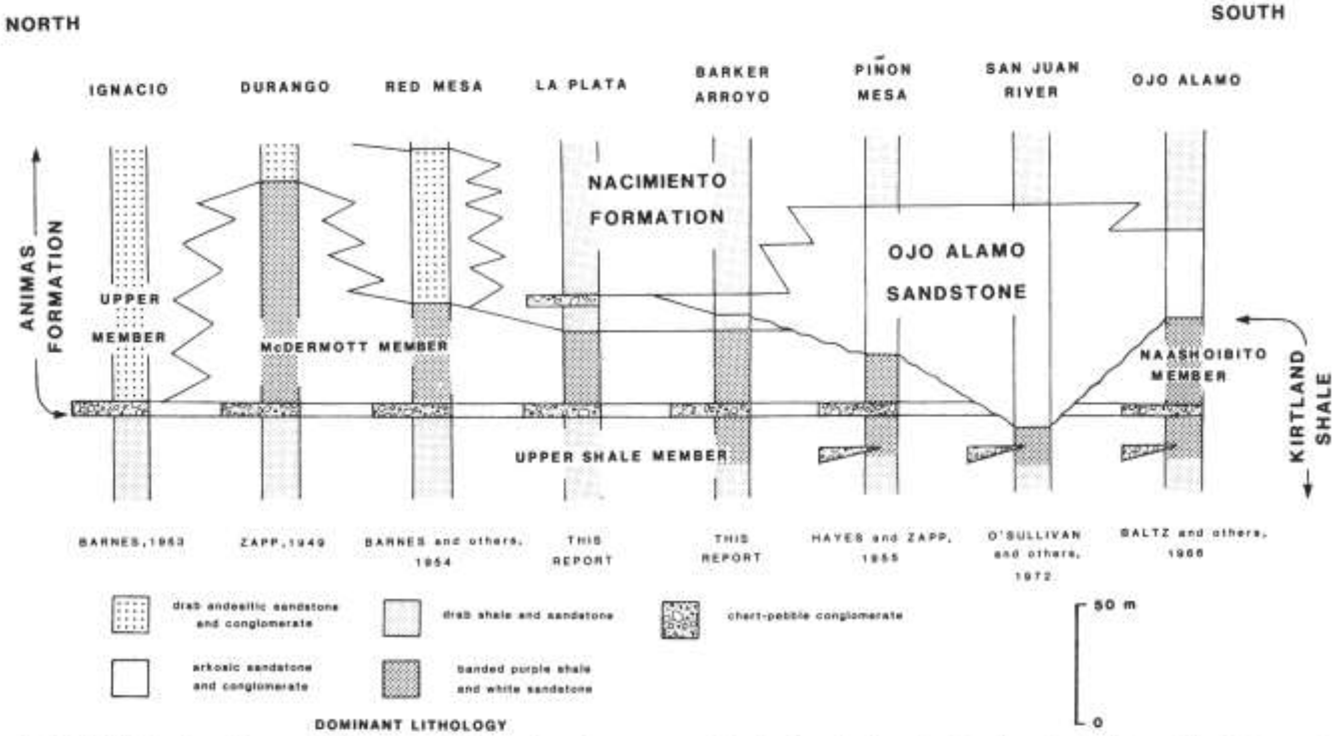

FIGURE 21—Stratigraphic correlation chart of the north and west parts of the San Juan Basin, showing the relationships of the McDermott and Naashoibito to surrounding strata.

vation, the Ojo Alamo rests directly on drab-green and gray mudstone which is correlated with the upper shale member (see O'Sullivan et al., 1972; O'Sullivan and Beaumont, 1957).

Just south of the San Juan River, at Farmington, banded purple mudstone and white sandstone reappear beneath the Ojo Alamo. These beds are about 10 m in thickness and contain a zone of scattered siliceous pebbles (see Reeside, 1924: 62; O'Sullivan et al., 1972: 53). Most stratigraphers have included these strata within the upper shale member of the Kirtland. Reeside (1924), however, equated them with the McDermott Formation (now the McDermott Member of the Animas Formation sensu Barnes et al., 1954) of the northern San Juan Basin.

The equivalence of the McDermott Member with rocks of the upper part of the Kirtland Shale south of the San Juan River has been a point of disagreement among stratigraphers (see Baltz et al., 1966). The McDermott typically consists of a lower conglomeratic sandstone with siliceous pebbles overlain by intertonguing banded purple and gray mudstone and by soft, clay-rich, conglomeratic white sandstone with abundant andesitic detritus (Reeside, 1924; Zapp, 1949; Barnes, 1953; Barnes et al., 1954; Hayes and Zapp, 1955). The McDermott is very similar to the Naashoibito lithologically and in the superposition and interrelationships of its lithofacies, and is equivalent to the Naashoibito in its relative stratigraphic position. Although their equivalence cannot be demonstrated by physical tracing of beds, it seems likely that the McDermott and Naashoibito are parts of the same genetic unit, which is, however, no longer contiguous in exposure. As suggested above, and in what follows, erosion prior to deposition of the Ojo Alamo Sandstone has removed the equivalent strata from intervening areas.

Although the basal siliceous conglomeratic sandstone of the McDermott, like that of the Naashoibito, rests on a channeled erosional surface, all authors agree that there is no substantial unconformity at its base. The presence of this thin, persistent, conglomeratic sandstone throughout the northern San Juan Basin and its probable equivalence with the basal conglomerate of the Naashoibito make it a useful tool for correlation (Fig. 21). There are, however, scattered lenses of siliceous pebbles in the sandstones of the upper shale member of the Kirtland below the McDermott (Barnes et al., 1954; O'Sullivan et al., 1972) and below the Naashoibito (this report). Such occurrences are, however, restricted to local channels and are not persistent as in the McDermott/Naashoibito conglomerate.

In the Ignacio area of Colorado (Fig. 21) the McDermott Member is not separated from the rest of the Animas Formation. The contact of the Animas with the Kirtland Shale is, however, marked by the same thin chert-pebble conglomerate (Barnes, 1953). Traced westward, this conglomerate underlies the drab-colored upper member of the Animas to just east of Durango, where the purple beds of the McDermott Member begin intertonguing with, and underlie, the upper member of the Animas (Zapp, 1949).

The McDermott is about 100 m thick in the Durango area (Reeside, 1924; Zapp, 1949). The basal conglomeratic sandstone is here generally 1-2 m thick, but in places it fills channels up to 20 m thick (Zapp, 1949). The McDermott is thickest, and contains the coarsest andesite cobbles and boulders, in the Durango area, suggesting that a nearby source terrain for these sed-

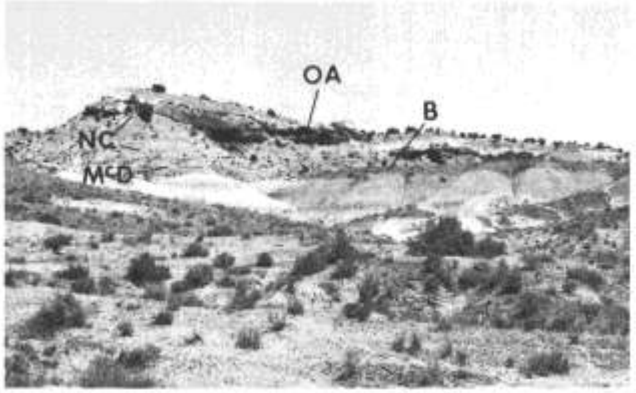

FIGURE 22—Northernmost exposure of the Ojo Alamo Sandstone (**OA**) on Barker Arroyo where it overlies a tongue of the Nacimiento Formation (**NC**) and the McDermott Member of the Animas Formation (**McD**). The dark basal conglomerate of the McDermott (**B**) holds up ridge in foreground. **Ku** = upper shale member of the Kirtland.

iments was just north of this area (see Reeside, 1924; Barnes et al., 1954). The McDermott thins and contains finer volcaniclastic sediment south and west from Durango.

In the Redmesa area of Colorado the McDermott is about 30 m thick, but in places it is completely replaced by intertonguing with the drab-colored upper member of the Animas (Barnes et al., 1954). Near the Colorado—New Mexico state line the upper member of the Animas intertongues with, and is eventually replaced by, similar drab-colored shale and sandstone of the Nacimiento Formation (Baltz et al., 1966). The McDermott Member, however, persists beneath the Nacimiento and remains approximately 30 m thick. Just above the lowest drab-colored strata in this area, a second thin chert-pebble conglomerate, similar to that at the base of the McDermott, appears. This conglomerate is persistent along McDermott Arroyo north and south of the state line and east of the La Plata River. Reeside (1924) chose this conglomerate as the boundary between the McDermott and Nacimiento Formations, although 5-10 m of drab-colored mudstone underlie the conglomerate at most places.

In Barker Arroyo, just north of Pinyon Mesa (Figs. 21, 22), the conglomeratic Ojo Alamo Sandstone appears as a southward-thickening wedge within the Nacimiento Formation and occupies the same stratigraphic position as the thin conglomerate on McDermott Arroyo. The two thus are probably equivalent (see Hayes and Zapp, 1955). In Barker Arroyo and along Pinyon Mesa at least 15 m of banded purple and gray mudstone and white sandstone with scattered siliceous pebbles underlie the basal conglomerate of the McDermott and are considered part of the upper shale member. The tongue of the Nacimiento Formation below the Ojo Alamo is about 5 m thick in this area, but southward along the La Plata River it is thinned and eventually truncated at the base of the Ojo Alamo near Pickering Arroyo (see O'Sullivan and Beikman, 1963).

The Ojo Alamo continues to thicken southward at the expense of the McDermott, which thins to about 20 m along the southern side of Pinyon Mesa (Fig. 23). The McDermott is truncated at the base of the Ojo Alamo immediately south of Pinyon Mesa (see O'Sullivan and Beikman, 1963). Along the San Juan River, near Farmington, the Ojo Alamo reaches its maximum thickness. The 10 m of banded purple mudstone and white sandstone with siliceous pebbles observed below the Ojo Alamo here (Reeside, 1924; O'Sullivan et al., 1972) are considered part of the upper shale member of the Kirtland.

If the banded purple-mudstone facies of the Naashoibito is a product of paleosol development, as suggested here, the presence of such beds alone is not a sound criterion for stratigraphic correlation. Soil-forming conditions which resulted in the distinctive banded purple mudstones existed locally prior to deposition of the Naashoibito and McDermott. Hence, the upper shale member exhibits a patchy distribution of this fades. These conditions became, however, more pervasive during Naashoibito and McDermott deposition, and the banded purple-mudstone facies became more widely distributed.

FIGURE 23—Mc
and the upper s
Ojo Alamo San
Jackson Lake.

Summary

Deposition of the McDermott–Naashoibito began at the onset of Laramide tectonism, when uplift and volcanism in the vicinity of the present San Juan Mountains shed siliceous and volcaniclastic sediments southward into the San Juan Basin. This was the beginning of the structural evolution of the San Juan Basin, which initiated a complete reversal in direction of pre-Maastrichtian drainage. Streams which formerly flowed northeastward toward the interior epeiric sea turned southwestward, resulting in the development of the present continental divide. The banded purple and gray overbank sediments, so typical of the floodplain deposits of these streams, record the initial formation of well-differentiated soils in the San Juan Basin. This, too, reflects uplift of the basin margins and perhaps the development of a basinward rain shadow (see Brown and Kraus, 1981).

Zapp (1949) suggested that the thin persistent zone of siliceous-pebble conglomerate which marks the base of the McDermott (and Naashoibito) was ". . . derived from a residual mantle that was swept from an old land surface to the north when the landmass was uplifted . . ." There is, however, no evidence that the Upper Cretaceous sedimentary pile was absent or thinner over the San Juan uplift, and consequently there is no evidence for an "old" land surface in the vicinity. Folding and faulting of Upper Cretaceous rocks, and at least 4000 ft of uplift in the San Juan region, was accomplished during Maastrichtian time (Dickinson et al., 1968). The entire Cretaceous sedimentary pile was eroded from the uplift during this time, because it was probably the Dakota Sandstone and Burro Canyon Formation which provided the abundant siliceous pebbles found in the McDermott, Naashoibito, and upper shale Members (Dickinson et al., 1968).

The enigmatic, widespread, thin, siliceous-pebble conglomerate of the basal McDermott–Naashoibito probably represents a lag deposit formed by erosional deflation. This deposit closely resembles sediments which overlie some pediment surfaces ("pedisediments" sensu Ruhe, 1975) and in some respects may be analogous to the buried "stone lines" of piedmont plains (see Ruhe, 1975). If this interpretation is correct, the importance of this conglomerate for correlation is increased. Although pediment surfaces and their associated deposits are widely known in Quaternary sediments, few attempts have been made to recognize pedisedimentary accumulations in ancient deposits (see, however, Stokes, 1950; Bluck, 1967).

The great aerial extent (originally perhaps as much as 100 km down-dip), gravelly composition, and extreme thinness (in places less than 1 m, usually about 2 m) of the basal McDermott–Naashoibito conglomerate are features held in common with pediment veneers, and consequently difficult to reconcile with more usual fluvial depositional processes. The basal conglomerate overlies a variety of lithofacies in the upper shale member of the Kirtland without significant change in lithology or apparent stratigraphic level. Its base is irregular, but only rarely contains deep channels; its top is sharp and approximates a horizontal surface. At most places its bedding is indistinct, but, as illustrated above by the yellow-conglomerate facies of the Naashoibito, it may exhibit characteristics of sandy braided-stream alluvium. In some areas, particularly in the northern San Juan Basin, this conglomerate suffered greatly under soil-forming processes, and is fraught with unstructured and heavily ferruginized clay skins and void fillings (Fig. 24).

Development of the basal conglomerate may have begun with the deposition of a thicker sequence of normal pebbly alluvium during the initial uplift of the San Juan region (Fig. 25, A). A period of tectonic quiescence followed, and the resulting lesser rate of subsidence in the basin caused the streams to incise their channels and the pebbly alluvium to be attacked by headward erosion of tributary drainages. As the exposures retreated, a relatively thin lag veneer of gravelly sand formed and eventually became the basal conglomerate (Fig. 25, B). Similar extensive gravel veneers form today in areas where the basal conglomerate and Ojo Alamo Sandstone are undergoing erosion.

Renewed uplift in the source terrain then caused rapid subsidence of the basin. Streams aggraded and the alluvial fill of the basin encroached on the veneered pediment surface, eventually burying it completely (Fig. 25, C). This second phase of uplift was accompanied by the intrusion and eruption of an andesite–rhyolite association of tuffs, breccias, and flows from the Ute, La Plata, Rico, and Ouray centers in the emergent San Juan volcanic field (see Larson and Cross, 1956; Dickinson et al., 1968). The newly formed volcanic highlands were immediately attacked by erosion, supplying streams flowing southward with abundant, coarse volcanic debris. The grain size of volcanic-rock fragments in the sediment decreased rapidly downstream, from boulder to cobble grade in the Durango area (McDermott) to granule and very coarse-sand grade in the Hunter Wash–De-Na-Zin Wash area (Naashoibito)—a distance of roughly 100 km. Comparable exponential downstream decrease in grain size occurs in streams draining volcanic regions today and is thought to reflect decreasing downstream flood-flow competence (Davies et al.,

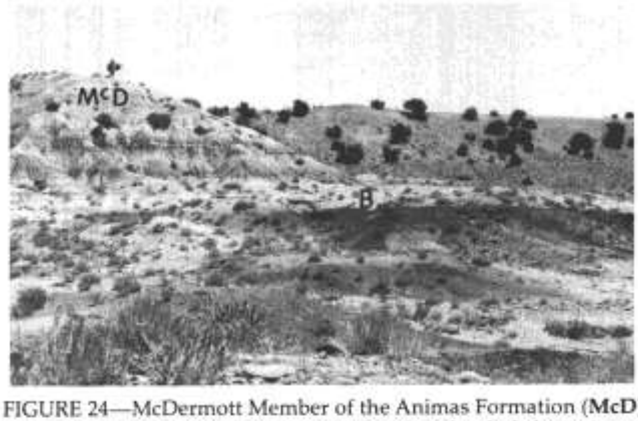

FIGURE 24—McDermott Member of the Animas Formation (**McD**) on the north side of Barker Arroyo, showing the dark ferruginous basal conglomerate (**B**).

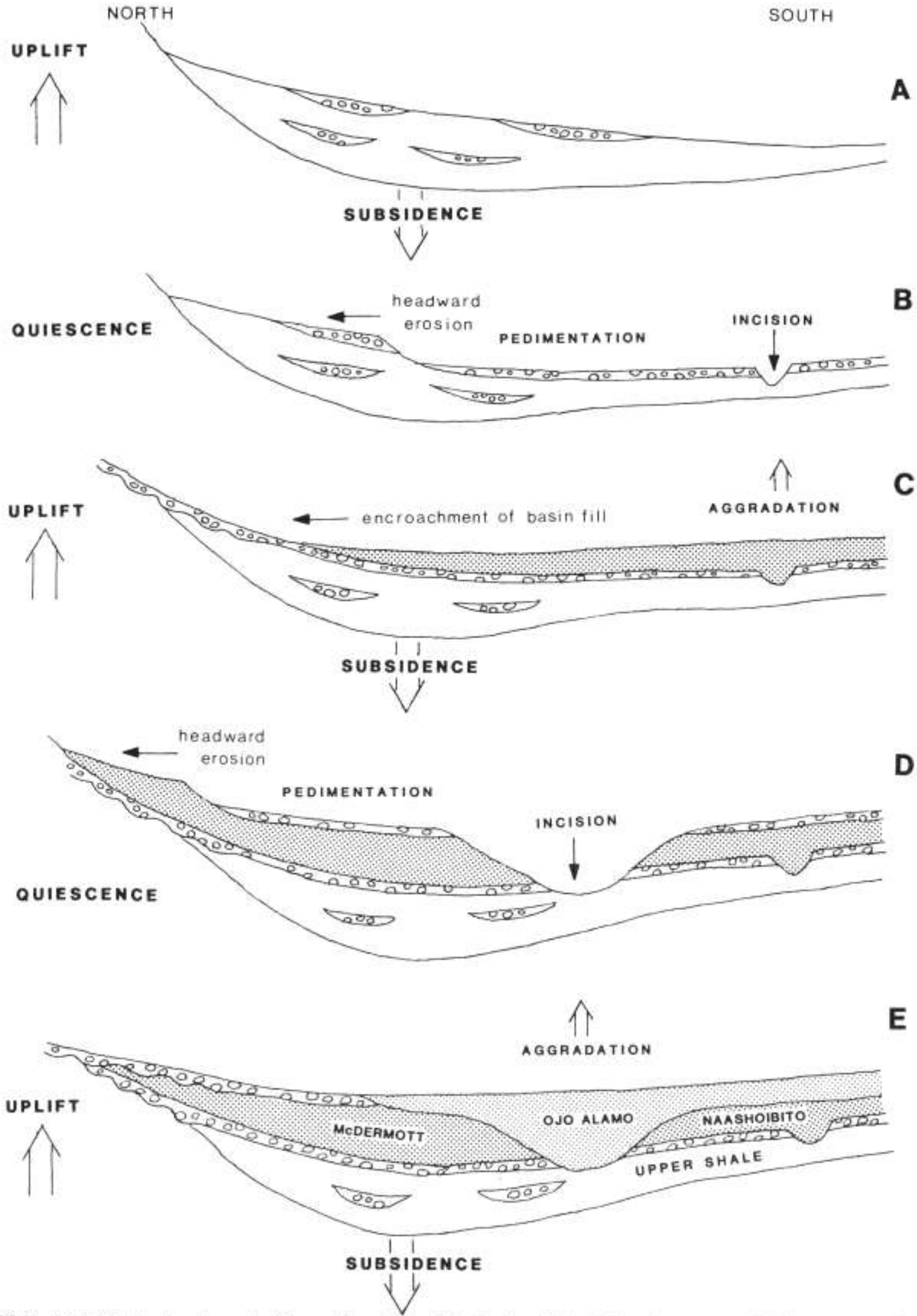

FIGURE 25—Model for the development of the northern flank of the San Juan Basin in Late Cretaceous and Paleocene times, showing alternating periods of uplift in the San Juan region accompanied by subsidence and aggradation in the basin, and periods of tectonic quiescence accompanied by erosional incision and pedimentation in the basin.

1978). In this case, however, volcanic pebbles must also have suffered higher abrasion than the chert and quartz pebbles which remain roughly constant in grain size downstream. The Naashoibito streams carried a considerable amount of volcanic ash as well.

Following this period of deposition, tectonic quiescence reoccurred, subsidence slowed, and streams incised deeply into the deposits of the McDermott and Naashoibito, completely removing them from the area of the present San Juan River and from most areas further south (Fig. 25, D). A small outlier in the present Hunter Wash-De-Na-Zin Wash area escaped erosion. Pedimentation occurred again, but the pedisediments formed at this time are preserved only north of Pinyon Mesa. During the early Paleocene, when uplift in the San Juan region began anew, the basin again subsided rapidly, incised channels were filled with coarse, braided alluvium, and deposits of a humid alluvial fan (Ojo Alamo Sandstone) were spread over virtually the entire basin (Powell, 1972; Fig. 25, E).

Conclusions

The interpretation presented above may help to resolve the current dispute over the Cretaceous-Tertiary boundary in San Juan Basin. Several points discussed here bear directly on this problem. 1) The Naashoibito Member may be considered an erosional outlier, genetically equivalent to the McDermott Member of the northern San Juan Basin. 2) There is a widespread, regionally angular unconformity at the base of the Ojo Alamo Sandstone, which represents a substantial hiatus that in most of the San Juan Basin includes the Cretaceous-Tertiary boundary. 3) In the northern part of the San Juan Basin and in the Hunter Wash-De-Na-Zin Wash area, sediments of late Maastrichtian (Lancian) age—the McDermott and Naashoibito—escaped pre-Ojo Alamo erosion and are preserved beneath the Ojo Alamo or its equivalent. In these areas, sedimentation was virtually continuous along the Cretaceous-Tertiary boundary. 4) Thus, the magnetostratigraphic-polarity column compiled by Lindsay et al. (1978) does, as they contend, represent a nearly complete section through the Cretaceous-Tertiary boundary.

Consequently, points raised by both sides in the dispute are correct. There *is* a regional unconformity at the base of the Ojo Alamo which coincides with the Cretaceous-Tertiary boundary. However, in some areas (the Hunter Wash area is fortuitously one of these) the hiatus represented by this surface is of relatively short duration and may be considered diastemic.

Appendix

Identity of specimens noted in measured sections of Fig. 3. UNM = specimens in the collections of the University of New Mexico, USNM = U.S. National Museum.

Measured section	Specimen number and description
2	P = UNM B-513, ?*Pentaceratops* braincase fragment
	A = UNM B-522, *Alamosaurus* distal caudal centrum
3	A = uncollected, *Alamosaurus* femur
	T = uncollected, ?*Torosaurus* caudal vertebrae
4	T = UNM B-628, *Torosaurus* left squamosal
6	A = uncollected, *Alamosaurus* femur
	T = UNM FKK-001, *Torosaurus* squamosal fragment
7	T = UNM B-640, *Torosaurus* skull fragments
11	A = UNM B-656 and UNM FKK-003A–G, *Alamosaurus* teeth
12	A = UNM B-709, *Alamosaurus* juvenile left scapula
	C = coprolite locality noted in text
13	A = UNM FKK-034, *Alamosaurus* tooth
	A = USNM 10486, 10487, and 15658, *Alamosaurus* left scapula, right ischium, and distal caudal vertebra UNM FKK-029, *Alamosaurus* tooth UNM FKK-033, *Alamosaurus* femur
	T = UNM FKK-031, *Torosaurus* right squamosal
14	P = UNM FKK-035, ?*Pentaceratops* juvenile right squamosal and parietal fragments
	A = uncollected, *Alamosaurus* ilium and ribs
	T = UNM FKK-013, *Torosaurus* parietal fragment
15	T = UNM FKK-082, *Torosaurus* supraorbital horncore (braincase and skull fragments subsequently lost)

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Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, μm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}
Pressure, stress		
lb in^{-2} (= lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (= kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0° C)
inches of Hg (at 0° C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	m^2 sec^{-1}
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units, BTU	2.52×10^{-1}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F − 32	5/9	°C (Celsius)

**Divide by* the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929.

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