Macroinvertebrate paleoecology of a transgressive marine sandstone, Cliff House Sandstone (Upper Cretaceous), Chaco Canyon, northwestern New Mexico

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MACROINVERTEBRATE PALEOECOLOGY OF A TRANSGRESSIVE MARINE SANDSTONE, CLIFF HOUSE SANDSTONE (UPPER CRETACEOUS), CHACO CANYON, NORTHWESTERN NEW MEXICO*

by

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INTRODUCTION

This paper is a preliminary report on the stratigraphy and fauna of the Cliff House Sandstone (Upper Cretaceous) in Chaco Canyon, New Mexico. The exceptionally well exposed strata of the Cliff House Sandstone in the Chaco Canyon National Monument area (Fig. 1) are profusely fossiliferous, containing a diverse macroinvertebrate fauna and abundant trace fossils. The several distinctly different fossil assemblages which we have recognized are described and interpreted herein. This study of fossil assemblages in the Cliff House Sandstone at Chaco Canyon is intended to establish a datum for the comparison of Cliff House fossil accumulations presently being investigated throughout San Juan Basin.

Figure 1. Index map showing boundary of Chaco Canyon National Mounument and general distribution of the Cliff House Sandstone (Kch) and related sandstone units in San Juan Basin area of northwestern New Mexico. The upper sandstone unit of the Mesaverde Group is mapped as the La Ventana Sandstone (Klv) in the southeastern corner of the basin. The Mesaverde (Kmv) is shown mapped as one unit along the eastern margin of the basin. Geology modified from the Geologic Map of New Mexico by Dane and Bachman (1965).

STRATIGRAPHY

Stratigraphic Framework

General stratigraphic relationships of Upper Cretaceous strata in the San Juan Basin are well known. The major stratigraphic units of the western part of the basin are listed below, as recognized by Reeside (1924):

	Kirtland Formation
	Fruitland Formation
	Pictured Cliffs Sandstone
	Lewis Shale
	Cliff House Sandstone
Mesaverde	Menefee Formation
Group	Point Lookout Sandstone
	Mancos Shale
	Dakota Sandstone

These units record a complex history of transgressive and regressive migrations of the Upper Cretaceous shoreline in the area of the present-day San Juan Basin. Several of the major units described by Reeside (1924) have been subdivided (especially the Mancos—Mesaverde interval) and understanding

of their stratigraphic relationships has been refined considerably as a result of numerous studies over the past 50 years. Beaumont (1971) has presented an up-to-date comprehensive discussion of the conceptual transgressive-regressive model for Upper Cretaceous deposition in the San Juan Basin area, as originally presented in the classic papers by Sears and others (1941) and Pike (1947).

The Menefee-Cliff House-Lewis stratigraphic interval records a southwestward transgression of the Western Interior sea. The vertical and lateral relationships of these three lithosomes across the Chaco Canyon-Chacra Mesa area are similar to those schematically illustrated in Figure 2. The coal-bearing coastal
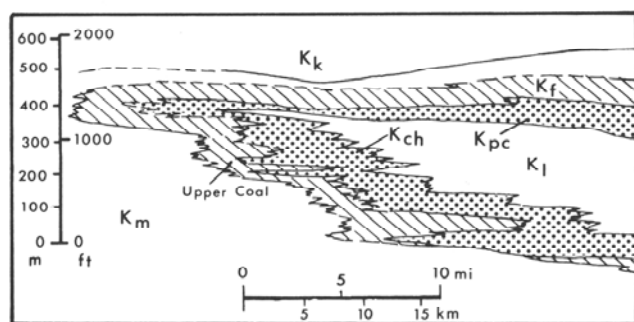

Figure 2. Schematic SW-NE stratigraphic diagram showing relationships of Upper Cretaceous units in the southwestern part of San Juan Basin: Km, Menefee Formation, including upper coal-bearing part (cross-ruled pattern below Kch); Kch, Cliff House Sandstone; Kl, Lewis Shale; Kpc; Pictured Cliffs Sandstone; Kf, Fruitland Formation; Kk, Kirtland Formation. Modified from Beaumont (1971, fig. 6).

plain (deltaic?) sediments of the upper part of the Menefee Formation (30-50 m locally well-exposed in the canyon walls) are intertongued with and overlain by the transgressive marginal-marine sandstone and shale of the Cliff House. The Cliff House, in turn, grades laterally and vertically into the offshore marine sediments of the Lewis Shale. It is noteworthy that Chaco Canyon is located near the southwestern depositional limit of the Cliff House Sandstone. The Lewis Shale is only about 30 m thick in the study area and is overlain by the Pictured Cliffs Sandstone just north of the National Monument boundary (Fig. 3). Although now removed by erosion, the "turnaround point," where the Lewis pinches out and the transgressive Cliff House merges with the regressive Pictured Cliffs Sandstone, was located only a short distance southwest of Chaco Canyon. The Cliff House Sandstone section at Chaco Canyon is anomalously thick (averaging about 90 m), as compared with the rest of the San Juan Basin and probably represents a relatively stationary shoreline near its transgressive limit, during which time the marginal-marine sand could accumulate to a considerable thickness. It is quite probable that a likewise thick coal-bearing interval of Menefee was deposited a short distance south and southwest of the Chaco Canyon-Charca Mesa area (Beaumont and Shomaker, personal communication, 1974); that interval has since been removed by erosion.
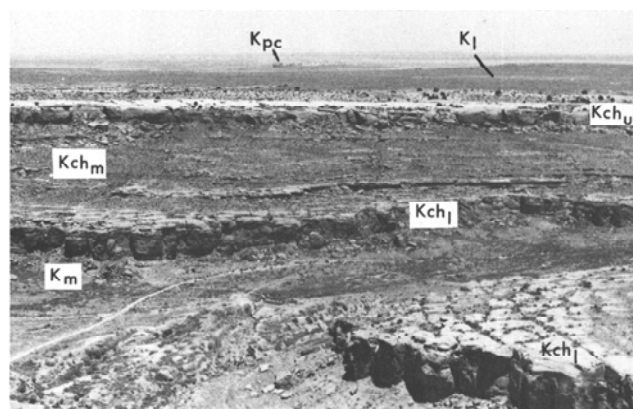

Figure 3. Low-angle oblique air photo (view approx. N 10° W) of stratigraphic units along north side of Chaco Canyon (opening of Mockingbird Canyon into Chaco Canyon; SW ¼ sec. 17, T. 21 N., R. 10 W.). Cliff House Sandstone (over-all thickness here approximately 90 m) is subdivided into lower cliff-forming sandstone unit (Kch$_l$), middle slope-forming sandstone and shale unit (Kch$_m$), and upper cliff-forming sandstone unit (Kch$_u$). Upper unit also includes the light-colored, irregular cliff- and slope-forming sandstone above the upper cliff and is overlain by the poorly-exposed, soil-covered Lewis Shale (Kl). An exposure of the Pictured Cliffs Sandstone (Kpc) is visible in the distance. The upper few meters of the Menefee Formation (Km) is exposed below the lower cliff. Canyon floor is underlain by Holocene alluvium.

Age of the Cliff House Sandstone at Chaco Canyon and Rate of Transgression

At Chaco Canyon the Cliff House Sandstone contains abundant specimens of the ammonoid cephalopod *Buculites perplexus* Cobban, which, according to Gill and Cobban (1966, table 2), occurs in lower (but not lowest) Upper Campanian strata (estimated age 77 million years). In the type area (Mesa Verde, Colorado) the Cliff House contains *Baculites macleami* Landes, an index to lowest Upper Campanian strata (Gill and Cobban, 1966, plate 4) which have an estimated age of 79.5 million years (Gill and Cobban, 1966, table 2). The above "estimated ages" are based on interrelated biostratigraphic and radiometric age data.

Thus, the Cliff House Sandstone at Chaco Canyon is approximately 2.5 million years younger than the Cliff House Sandstone at Mesa Verde. If it is assumed that the depositional strike of the Cliff House shoreline was approximately N 60° W, the distance of shoreline migration between Mesa Verde, Colorado and Chaco Canyon, New Mexico was about 80 km (50 miles). We can then speculate that the average rate of transgression was about 32 km (20 miles) per million years (approximately 1 km/30,000 yrs, or 3 cm/yr).

Stratigraphic Units at Chaco Canyon

At Chaco Canyon the Cliff House Sandstone varies in thickness from about 85 to 94 m. Locally as much as 50 m of the uppermost part of the Menefee Formation is well exposed beneath the Cliff House. North of the canyon the Lewis Shale forms a broad, soil-covered slope, but on the mesas just south of the canyon the Lewis and upper few meters of the Cliff House have been removed by erosion (Fig. 4).
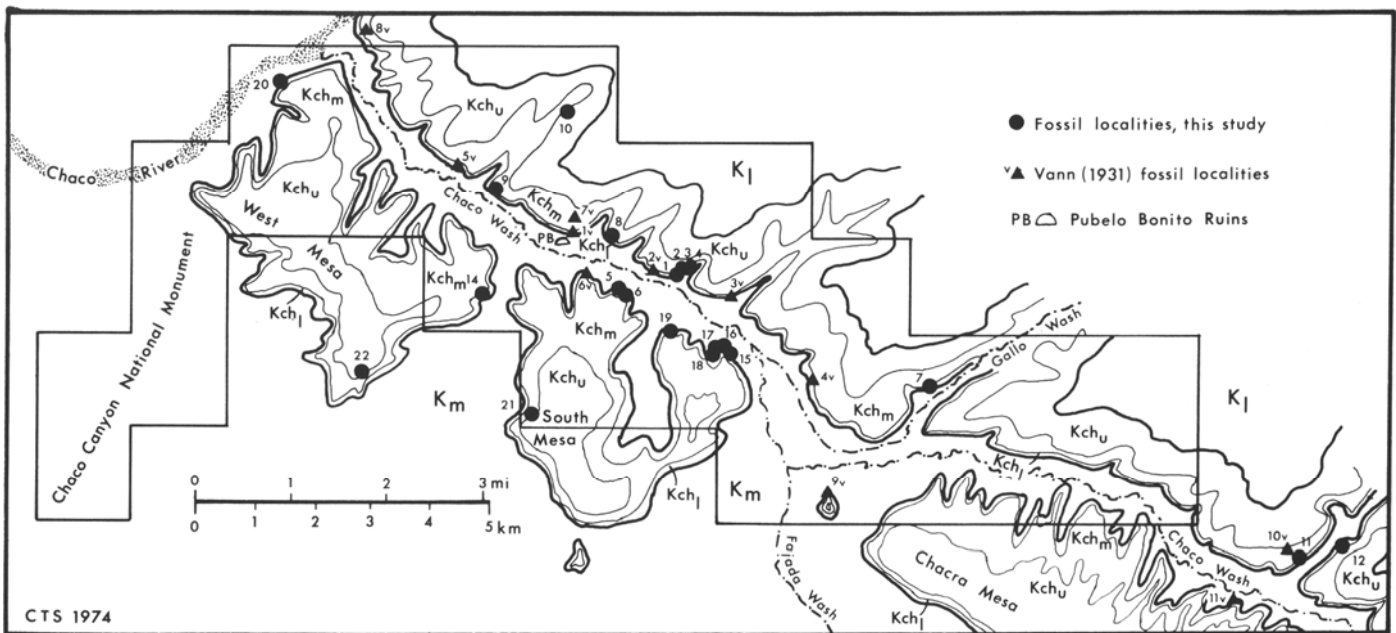
Figure 4. Generalized geologic map of Chaco Canyon National Monument area showing fossil localities of Vann (1931) and this study; detailed locality information in Appendix. Formation symbols same as in Fig. 3. Map compiled from Kin Klizhin Ruins, Pueblo Bonito, and Sargent Ranch, New Mexico 7½' Quadrangle maps and aerial photos loaned by Chaco Center, University of New Mexico.

Along most of the south-facing scarps of West Mesa, South Mesa and Chacra Mesa the Cliff House Sandstone consists of a sequence of thick, cliff-forming sandstone units and slope-forming sandy shale and shaly sandstone units. At Chaco Canyon three subunits of the Cliff House Sandstone, hereafter referred to as the lower, middle and upper units, are generally well defined throughout the canyon and along Chacra Mesa (Fig. 3). These units show relatively little lithologic variation along depositional strike; however, there is considerable variation, especially in the middle unit, at right angles to the depositional strike.

The lower and upper sandstone units are everywhere cliff-formers. The lower unit forms a cliff 20-30 m high which dominates the view from within the canyon. This unit is composed of friable, orange-weathering, very fine grained, generally well-sorted sandstone which displays low-angle (less than 10°) cross-stratification. Large, brown-weathering, oblate-spheroidal, calcite-cemented sandstone concretions (Fig. 5) and a few thin calcite-cemented sandstone beds are locally abundant. Such conspicuous beds and concretions are the most fossiliferous parts of the Cliff House. Except for the upper 10 m, the upper cliff-forming unit is similar to the lower one. The top 10 m of the upper unit, however, is an extremely friable, light-colored (almost white), moderately high-angle cross-stratified sandstone that is slightly coarser grained and better sorted than underlying sandstones of the upper unit.

On the north side of the canyon, the middle unit contains numerous beds of soft sandy shale and clayey sandstone and siltstone. These are interbedded with resistant sandstones which are similar to those in the lower unit. Because of the non-resistant character of the shaly beds, the middle unit generally forms a slope between the lower and upper cliffs (Fig. 3). Toward the south there is a profound facies change within the middle unit. At the southernmost exposures, along the south-facing West Mesa, South Mesa and Chacra Mesa scarps, the middle unit is an interval of thin, light-colored,

high-angle cross-stratified lenses of sandstone, and interbedded sandy carbonaceous shale and lignite. Thus, to the north the middle unit resembles the Lewis Shale, and to the south it resembles the Menefee Formation, illustrating the laterally intertongued relationship of those two units with the Cliff House Sandstone.

The lower Menefee-Cliff House contact is generally a conformable one and commonly sharp, and is usually placed just above the highest lignite seam or bed of carbonaceous shale and near the base of the lower cliff-forming, orange-weathering sandstone. The contact of the middle and upper units of the

Figure 5. Slightly ferruginous, calcite-cemented sandstone concretions at top of lower, cliff-forming sandstone at fossil locality 16; Assemblage 1 fossil accumulation in lower part of concretions. Paleontologist at lower right is 177 cm (5 ft. 10 in.) tall.

Cliff House is similar to that of the lower unit with the Menefee.

The underlying Menefee Formation exposed at Chaco Canyon is characterized by lenses of light-colored, friable, fine- to very fine-grained, moderately well sorted sandstone with moderately high-angle (15-20°) cross-strata. These are interbedded with carbonaceous shale, weathered lignite and thin low-grade coal seams. Orange-red clayey sandstone beds, which result from burned out coal seams, are locally abundant in the Menefee, although not particularly common in the main section of the Chaco Canyon National Monument area.

Sandstones in all of the units, including the Menefee, consist of about 65-70 percent sand- and silt-size framework grains and 30-35 percent void space, matrix and cementing material. The framework is commonly composed of 55 to 65 percent quartz, 25 to 40 percent rock fragments and 5 to 10 percent feldspar. Rock fragments are predominantly chert and other sedimentary rock types (especially shaly siltstone and silty claystone and shale). A few volcanic fragments are also always present. Significantly, transported dolomite rhombs are commonly quite abundant (up to 15% of all framework grains) in the cliff-forming Cliff House Sandstone units, but are absent in the Menefee sandstones and in the upper light-colored sandstone of the upper unit.

Matrix and/or cementing material is mainly iron oxide and iron-stained clay, but there is some silica and calcite cement. Calcite is especially abundant in the large concretions. Clays are mainly authigenic kaolinite but also include occasionally abundant illite, Ca-montmorillonite and mixed layer illite-montmorillonitc. Pore space also comprises much of the non-framework portion of the sandstones. Porosities usually range from 25 to 30 percent (over 25 samples were analyzed by Core Lab, Denver).

The Lewis Shale is very poorly exposed in the study area. Where observed it consists of sandy and silty shale which contains isolated calcareous concretions. Clay minerals in the Lewis Shale are predominantly Na-montmorillonite but also contain some illite and mixed layer illite-montmorillonitc and a little kaolinite.

THE MACROINVERTEBRATE FAUNA

The Collections

Reeside (1924) listed fossils collected at a site (USGS 9743) near Pueblo Bonito in Chaco Canyon National Monument. Although we collected from the same locality, our account of the fauna differs from his in several respects which cannot be attributed solely to changes in taxonomic nomenclature. Vann (1931) reported on the paleontology of Chaco Canyon in a master's thesis submitted to the University of New Mexico. Vann's material, along with material collected by us at 22 localities in the canyon (Fig. 4, Appendix), has been utilized in the present study. More than 50 invertebrate taxa, mostly molluscan, are represented in the combined collections, and there are probably more species yet to be found.

In every fossil that we examined the original shell material is missing or has been altered to blocky, coarsely crystalline calcite. Because of the hard, brittle character of the enclosing matrix, fossils showing all taxonomic characters are difficult to obtain. Most specimens that have been collected are merely incomplete internal molds. Dentition, muscle scars, and traces of the pallial line have not been observed for several of the bivalves, and apertural features have not been observed for

some of the gastropods. Owing to these limitations many of our preliminary taxonomic determinations are uncertain. Nevertheless, the taxa listed in Table 1 have been identified.

Of the identified taxa, *Idonearca* sp., *Pycnodonte (Phygraea)* ex gr. P. (P.) *vesicularis* (Lamarck), *Exogyra* aff. E. *ponderosa* Roemer, and *Valetella?* sp. were present in the collection attributed to Vann (1931) but were not individually labeled as found at Chaco Canyon by Vann. None of these taxa were found by us in the present study. Consequently, we cannot discount the possibility that Vann's collection has become contaminated with extraneous material. However, because we have no positive evidence to the contrary, we have assumed that they are indeed from the Cliff House Sandstone at Chaco Canyon.

General Significance

Although the Cliff House fauna is quite diverse in comparison with many other Western Interior faunas, sandstone units in the Gulf Coast region commonly contain even more diverse faunas. For example, Wade (1926) collected 114 species of bivalves and 174 species of gastropods (164 species reported by Sohl, 1960 and 1964) from the Coon Creek Tongue of the Ripley Formation in Tennessee, and Stephenson (1941) described 106 species each of bivalves and gastropods from the Nacatoch Sand in Texas. Sohl (1967a, p. 4) noted, however, that more commonly 40 to 50 species of gastropods are present in collections from such units as the Ripley and Owl Creek Formations in the eastern Gulf Coast region. Nevertheless, Western Interior faunas are significantly less diverse than those of the Gulf Coast. Sohl (1967a, p. 4) suggested that gastropod diversity in the Western Interior may have been restricted by scarcity of algae. *Anisomyon* is the only algae-feeder in the Cliff House gastropod suite.

Sohl (1967a) listed taxonomic groups in all Western Interior Cretaceous sandstone assemblages in order of frequency of occurrence in collections that he examined. For each faunal group, bivalves, gastropods, and cephalopods considered separately, the over-all Cliff House fauna is similar in virtually all respects to the total sandstone assemblage as characterized by Sohl (Table 2). Because we have recognized four different kinds of assemblages in the Cliff House, the following comments refer only to the over-all composition of the fauna. Of course, where faunas collected from individual formations and at single localities are considered, exceptions to the general pattern are to be expected.

The Cliff House fauna is dominated by shallow-water marine elements. Thus, it is notable that the fresh-water gastropod *Oreohelix?* is the second most abundant gastropod. The pupiform land snail *Holospira* also is common. Rare, probable brackish-water (N. F. Sohl, personal communication, 1973) gastropods in our collection include two genera, *Pachymelania?* and the neritid *?Velatella.* Mixed gastropod faunas have been found elsewhere in the Western Interior region, as in the Almond Formation (Upper Cretaceous) in Wyoming (Sohl, personal communication, 1973). The fresh-water gastropod *Melania* is among the commonest forms in mixed assemblages in the Fox Hills Sandstone (Upper Cretaceous) in northern Colorado (Sohl, 1967a, p. 23). Because no fresh-water or unequivocally brackish-water bivalves *(Crassostrea* is euryhaline) occur in the Cliff House at Chaco Canyon, we believe that the non-marine gastropods were washed in.

Table 1. Macroinvertebrate taxa and trace fossils identified in Cliff House Sandstone at Chaco Canyon, New Mexico.

MOLLUSCA:

Bivalvia:
Nucula? sp.
Yolida? sp.
Anadara? sp.
Idonearca sp.
Inoceramus barabini Morton (s.l.)
I. pertenuis Meek & Hayden
I. sagensis Owen
I. cf. I. simpsonis, (Meek (s.l.))
I. tenuilineatus Hall & Meek
I. vanuxemi Toumey (s.l.)
Oxytoma sp.
Pycnodonte (Phygraea) ex. gr.
    P. (P.) vesicularis (Lamarck)
Exogyra aff. E. ponderosa Roemer
Ostrea plumosa Morton
Crassostrea subtrigonalis (Evans & Shumard)
Parvilucina? aff. ?P. linearia (Stephenson)
Granocardium (Ethmocardium) whitei (Dall) (s.l.)
Cymbophora aff. C. alta (Meek & Hayden)
?C. simpsonensis Stephenson
Hercodon n. sp.
Tellinimera n. sp.
Arcopagella n. sp.
Protodonax chloropagus Vokes
P. exaquilius Vokes
P. n. sp. A
P. n. sp. B
indeterminate genus belonging to the Veneridae
Parmicorbula ? sp.

Gastropoda:
Velatella? sp.
Oreohelix? sp.
Euspira obliquata (Hall & Meek)
Banis cf. B. siniformis Stephenson
Spironema cf. S. perryi Stephenson
Trachytriton? sp.
indeterminate genus belonging to the Cymatiidae
Parafusus sp.
Volutomorpha retifera Dall
Pachymelania? sp.
Holospira sp.
Anisomyon borealis (Morton)
A. cf. A. sexsulcatus Meek & Hayden

Cephalopoda:
Baculites perplexus Cobban
Placenticeras intercalare Meek

ECHINODERMATA:

Echinoidea:
Hardouinia taylori (Warren)

TRACE FOSSILS:

Plant Structures:
Reed(?) Molds

Burrows and Trails:
Ophiomorpha-Thalassinoides
Gyrochorte
Chondrites

Borings:
Teredolithus
Polydorid borings
Clinoid borings

Table 2. Comparison of Cliff House assemblage with total Western Interior sandstone assemblage. Listed in approximate order of abundance.

Faunal Group	Cliff House Sandstone Chaco Canyon	*all Cretaceous sandstones Western Interior
bivalves	Ostreidae	Cardiidae
	Mactridae	Inoceramidae
	Cardiidae	Crassostrea
	Inoceramus	Cyprimeria-Tapes
	Protodonax	Tellinidae
		Mactridae
		Cucullaea
gastropods	Banis	Gyrodes
	Oreohelix?	Volutidae
	Euspira	Euspira
	Spironema	Fasciolariidae
	Volutomorpha	Arrhoges-Anchura
	Anisomyon	Turritella
		Buccinidae
		Pyropsis
cephalopods	Baculites	Placenticeras
	Placenticeras	Baculites
		Scaphites

*modifed from Sohl (1967a)

Although *Anisomyon* belongs to a pulmonate group, the genus is common in many undoubted marine rocks in the Western Interior, and is presumed to have become readapted to a marine habitat (Sohl, 1967b).

Although naticids *(Banis, Euspira,* and *Spironema)* collectively dominate the Cliff House gastropod suite, no snail-bored bivalves were found. Sohl (1967b) observed a similar situation in the Pierre Shale at Red Bird, Wyoming. Apparently naticids in the Cliff House and Pierre had not developed the shell-boring habit displayed by modern members of the family.

The trace fossils observed in the Cliff House Sandstone at Chaco Canyon are rather typical of Western Interior shallow-water marine and marginal-marine sedimentary units. Relatively large (2-5 cm diameter), iron-cemented *Ophiomorpha* is the most conspicuous biogenic component of the Cliff House. The typical *Ophiomorpha* structure (vertical, hollow, cylindrical, knobby exterior wall and smooth interior) commonly merges with a horizontal Y-branched burrow system (Fig. 6) which, when separated from the vertical *Ophiomorpha* and especially when lacking knobby ornamentation, is usually classified as *Thalassinoides.* However, both structures were obviously constructed by the same kind of organism, probably the same species in this case. These structures are comparable with those made by the modern decapod crustacean *Callianassa* which inhabits most commonly the marine mid-intertidal but also occurs in very shallow-water marine bays and in subtidal shallow shelf environments (see Hoyt and Weimer, 1964). *Gyrochorte* is a sinuous, bilobate trail probably made by browsing gastropods; such structures are very common on modern tidal flats. The shell-boring structures are probably attributable to polydorid annelids and/or clinoid sponges; both are common in the modern shallow marine and coastal marine to brackish bays. *Teredolithus* structures in fossil wood result from toredid boring, the occurrence of which strongly suggests brackish to marine conditions. Such bored wood of course can

Figure 6. Y-branched, horizontally-oriented Ophimorpha (-Thalassinoides) burrow structure with well-developed, ferruginous, knobby-exterior wall, weathering out of friable sandstone. Scale is 15 cm (6 in.) long.

be easily transported into and within a marginal marine setting. The plant structures referred to in general as "Reed(?) Molds" are indicative of coastal subaerial or swamp environments; such structures are commonly associated with lignitic and coal sediments in the Cliff House (middle unit) and underlying Menefee.

Fossil Assemblages at Chaco Canyon

Four distinct Cliff House assemblages of fossils have been recognized at Chaco Canyon. The assemblages are easily distinguished on the basis of faunal composition and stratigraphic occurrence within the Cliff House subunits as observed in the collections made by us. Because Vann (1931) did not subdivide the Cliff House, his material cannot be related to the deposition of the different lithologic subunits; however, most of his material apparently was collected from assemblage 1 type deposits in the lower sandstone unit (see Appendix). The principal characteristics and inferred origins of the assemblages are summarized in Table 3.

The stratigraphic occurrence of the fossil assemblages is par-

ticularly significant with respect to the over-all interpretation of the Cliff House depositional environments. Assemblage 1 is the most diverse and abundant of the four assemblages and occurs as highly fragmented accumulations (Fig. 7) mainly in the low-angle cross-stratified to sub-parallel stratified lower sandstone unit but also in the upper sandstone unit of the Cliff House. Counts of fragmented and unfragmented bivalves in assemblage 1 at four localities indicates that fragmented remains arc clearly more numerous than unfragmented remains (Table 4). The assemblage is best preserved in the large, slightly ferruginous, calcite-cemented sandstone concretions which occur throughout the lower and upper units but are especially abundant near the top of the lower unit (Fig. 5). Assemblage 2 has faunal elements similar to those of assemblage 1, but it is generally less diverse, and fossils are mostly unfragmented, although usually disarticulated and commonly current oriented (Fig. 8). Assemblage 2 was observed only in the thin sandstone beds in the lower part of the middle shaly unit on the north side of Chaco Canyon. The disarticulated and fragmented shell debris and scattered shark teeth and bone fragments of assemblage 3 (Fig. 9) occur in thin, but laterally persistent silty and clayey sandstone beds near the transitional boundary of the lower and middle units.

Assemblage 4 contains the least diverse fauna, being composed almost entirely of abundant Inoceramus (Fig. 10). The accumulations occur only at either the Menefee-Cliff House contact or the contact between the upper sandstone unit and the middle unit where it is composed of Menefee-like lithologes (lignitic and coaly sediments interlayered with high-angle cross-stratified sandstone lenses). Shells are commonly articulated and non-compressed and may be packed to a near maximum density in broad troughs up to 2 m high. Such troughs often extend into the underlying carbonaceous sediments and have scour bases. Cross-strata measured in several troughs reveal approximately 180-degree opposed bimodal paleocurrent patterns.

With the exception of in situ Reed(?) Molds, scattered woody material and abundant carbonaceous debris, the Menefee Formation was found to be devoid of fossil material. Teredolithus was not observed in the fossil wood deposits. Fresh-water molluscs also were not observed in these deposits.
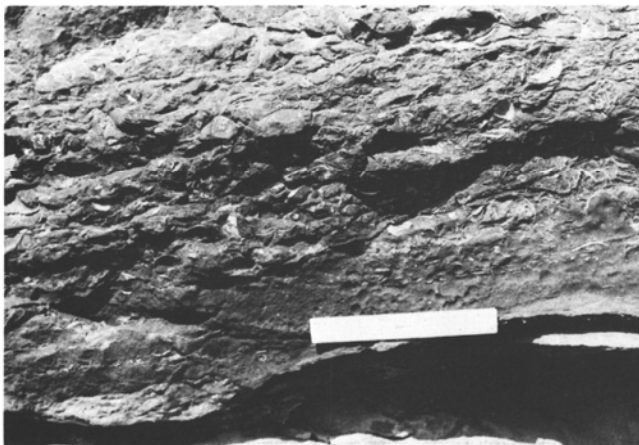

Figure 7. Assemblage 1 "fossil hash" accumulation in ferruginous, calcite-cemented sandstone concretion at fossil locality 16. Scale is 15 cm (6 in.) long.

Figure 8. Assemblage 2 fossil accumulation, mostly Inoceramus, in slightly ferruginous, calcite-cemented sandstone bed at fossil locality 9. Shells have been outlined with felt marker pen. Scale is 15 cm (6 in.) long.

Table 3. Characteristics and inferred origin of macroinvertebrate assemblages in Cliff House Sandstone at Chaco Canyon, New Mexico.

ASSEMBLAGE	CHARACTERISTIC TAXA	FRAGMENTATION AND ARTICULATION	ORIENTATION AND PACKING	LITHOLOGIC ASSOCIATIONS	INFERRED ORIGINS
1	Ostreidae, *Cymbophora*, Cardiidae, *Inoceramus*, *Protodonax*, Tellinidae, *Banis*, *Oreohelix?*, *Euspira*, *Spironema*, *Volutomorpha*, *Anisomyon*, *Baculites*, *Placenticeras*, vertebrate and woody material, *Ophiomorpha-Thalassinoides* (abundant), polydorid and clinoid borings	most bivalves either fragmented or abraded although there are numerous whole, fresh-appearing valves, including a few articulated *Cymbophora*	Commonly densely packed shell layers which extend laterally for several meters; shells have been piled one atop another; many are vertically oriented	only in the lower and upper cliff-forming sandstone units; occurs mainly in large, slightly ferruginous, calcite-cemented sandstone concretions and locally in thin, more or less continuous beds of ferruginous calcite-cemented sandstone beds near top of lower sandstone unit	transported, mixed assemblage, secondarily concentrated in the high-energy beach zone, representing elements of several communities
2	*Inoceramus*, *Granocardium* (*Ethmocardium*), *Cymbophora*, *Hercodon*, Ostreidae, and rarely *Banis*, *Volutomorpha*, *Placenticeras*; woody material, *Ophiomorpha-Thalassinoides* (present but only locally abundant), *Gyrochorte*, *Chondrites*	mostly unfragmented remains; disarticulated except for a few specimens in localized concentrations of *Inoceramus*; thin slightly ferruginous sandstone layers locally contain numerous small fragments of indeterminate molluscs	usually sparse, but tending to occur in clusters; bivalves are usually concave down and some shells appear to have been current-oriented	thin, slightly ferruginous, calcite-cemented (but not concretionary) sandstone beds in the middle shaly unit	relatively unmixed assemblage, transported only a short distance (if at all) in the shallow off-shore marine zone
3	*Crassostrea*, *Inoceramus*, shark teeth, bone debris	whole, disarticulated *Inoceramus*; whole and fragmented *Crassostrea*	widely scattered in fossiliferous unit with fossil material in various orientations	very thin (less than a meter) but laterally persistent silty and clayey sandstone beds near the transitional boundary of the lower sandstone and middle shaly unit	uncertain, but probably locally derived
4	*Inoceramus*, vertebrate and woody material with *Teredolithus*; rare *Placenticeras*, and encrusting oysters on *Inoceramus* shells.	abundant, unfragmented, articulated and disarticulated shells, commonly with numerous small fragments of *Inoceramus* shells at the base of accumulations	commonly closely packed in conspicuous shell accumulations; whole articulated *Inoceramus* may be stacked to a maximum density; line of commissure between articulated valves, and flat or elongate fragments commonly oriented parallel to base of beds	friable, orange-weathering sandstone filling broad channel-like lenses at or near the base of the lower and upper cliff-forming sandstone units where such units overlie carbonaceous and lignitic sediments of the Menefee and the middle Cliff House unit south of Chaco Canyon	tidal(?) channel-fill storm deposits and perhaps storm spillover-lobe deposits burying slightly brackish-water faunal elements

Table 4. Ratios of fragmented to unfragmented bivalves in assemblage 1 at four localities in lower, cliff-forming sandstone unit of the Cliff House Sandstone at Chaco Canyon, New Mexico.

TAXA	LOCALITIES				OVER-ALL RATIO (fragmented: unfragmented)
	F - 3	F - 4	F - 8	F - 16	
Ostreidae	257:70	64:24	148:17	31:5	4.3:1
Cymbophora aff. C. alta	212:20	62:9	96:2	262:10	15.5:1
Granocardium (Ethmocardium) whitei (s.l.)	11:5	17:12	103:18	7:5	3.5:1
Inoceramus	36:1	64:3	3:0	12:0	29.0:1
miscellaneous and indeterminate bivalves	no data	92:7	175:4	38:2	23.5:1
TOTALS	516:96	299:55	525:41	350:22	8:1

Figure 10. Assemblage 4; accumulation of whole, articulated Inoceramus shells in friable sandstone at fossil locality 15.
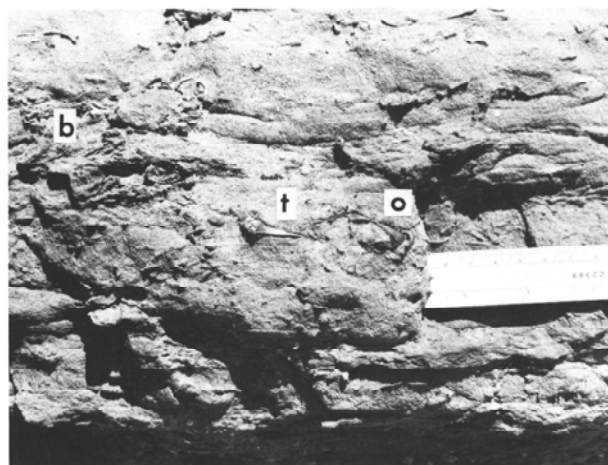

Figure 9. Assemblage 3; sandy siltstone bed containing fragmented oyster shells (o), shark teeth (t) and bone debris (b) at fossil locality 17. Scale in centimeter and inches.

Although the Lewis Shale has yielded marine fossils elsewhere, none were collected from the unit in the Chaco Canyon area.

PALEOENVIRONMENTAL INTERPRETATION

Modern relatives of the Cliff House molluscs live mostly in shallow marine environments. However, many of the Cliff House bivalves belong to families which today have representatives living in abyssal depths bordering the southern coastlines of North America, some ranging down to more than 3000 m (Parker, 1960 and 1964). Sediment types, sedimentary and biogenic structures (for example, abundant *Ophiomorpha)*, and the diversity of molluscan taxa suggest shallow, near-shore conditions. Some living relatives of the Cliff House bivalves and gastropods even extend into the intertidal zone. Presence of fresh-water and brackish-water gastropods suggests, in addition, proximity to major fresh-water influx and estuarine conditions.

Origin of Assemblages

Life habits of some of the Cliff House bivalves, inferred from shell form and comparison with modern relatives, suggests that more than one community is represented by assemblage 1. For example, similarity of shell form of modern

Donax and Cliff House *Protodonax* suggests similar modes of life for the two genera. *Donax* includes mainly species which are shallow burrowers in the intertidal zone of sandy beaches, and are adapted to life in shifting, sandy substrates. On the other hand, *Ethmocardium* and the small, indeterminate venerid were presumably adapted, as are modern cardiids and venerids having shell characteristics similar to their Cliff House counterparts, to life in relatively stable, sandy substrates. The deposit-feeders *Nucula?* and *Yolida?* in the Cliff House probably inhabited muddy sediments in somewhat protected environments.

In terms of diversity and lithologic association, assemblage 1 resembles the "diverse, nearshore, shallow-water marine mollusk assemblage" (Assemblage H) defined by Kauffman (1967) for older Cretaceous strata in the central Western Interior. According to Kauffman, that assemblage, which may contain more than 100 species, probably does not reflect any single community. Instead, it represents a varied fauna secondarily concentrated and derived from areas adjacent to the sites of deposition. Nearshore sands and sandy clays of the Atlantic coast today contain shell deposits formed in such a manner (Kauffman, 1967). Siemers has observed similar deposits on the barrier island beaches of the Texas Gulf coast and the Gulf of California coast of Sonora, Mexico.

Abundance of the large mactrid *Cymbophora* aff. C. *alta,* presence of numerous specimens of the thick-shelled tellinid *Hercodon,* and abundance of naticid gastropods suggests a parallel of the modern *Venus* community. In coarse, gravelly sand *Venus* communities are commonly dominated by large *Spisula* (a mactrid), and tellinids are represented by large species having relatively solid shells (Thorson, 1957, p. 508). Abundance also of *Ethmocardium* suggests an analogue of the modern *Tellina* community, characterized in the Cliff House by *Protodonax,* that may have occupied the intertidal beach and shallowest subtidal zones along the shoreline. A mud-bottom, quiet-water community, perhaps similar to the modern *Syndosmya* community, may be represented by Cliff House *Parmicorbula?, Nucula?* and *?Yolida.*

There is little evidence to suggest that assemblage 2 is derived from more than a single community. Exposure effects, especially fragmentation, are less pronounced in this assem-

blage than in assemblage 1. Probably the shells have not been transported far. Very small shell fragments are abundant in certain ironstone layers, however, but lack of intermediate-size fragments suggests that these were introduced. Composition of the assemblage is generally similar to that of the modern shallow-marine *Venus community.*

The origin of assemblage 3 is uncertain, but its limited diversity suggests derivation from a local environment characterized by a similarly restricted fauna. Such thin sandstone beds containing abundant bone debris have been interpreted elsewhere as true transgressive sand deposits (e.g., top of Dakota Group in Front Range area near Denver, Colorado; Weimer and Land, 1972, and personal communication 1974).

With the exception of rare *Placenticeras* and encrusting oysters, assemblage 4 contains only *Inoceramus.* At least four species, including *I. barabini* (s.1.), *I. pertenuis, I. tenuilineatus,* and *I. vanuxemi* (s.1.), are represented. Such low diversity suggests a relatively restricted environment. The occurrence of these fragile, articulated, mostly closed shells in troughs with bimodal cross-stratified sandstone strongly suggests that the animals were either living in tidal channels and buried by periodic rapid sedimentation, or that the living animals were swept up during storms and literally dumped into the channels. At least one occurrence of oysters encrusting the upper valve of an *Inoceramus* suggests *in situ* burial. The single fragmentary *Placenticeras* specimen could have been washed into an *Inoceramus* deposit during a storm. Associated sediments are similar to those of the cliff-forming units of the Cliff House (especially in that they contain dolomite grains; the Menefee does not) and seem to be devoid of burrow structures, also suggesting rapid deposition. Such tidal channels with shell-lag deposits and storm-fill deposits are common today between barrier islands along the Gulf coast of Texas and the Atlantic coast of Georgia (Bernard and others, 1970; Cooper Land, personal communication 1974). Shifting barrier islands fill in the deep migrating channels which may scour down into older units.

Deposition of the Cliff House Sandstone

The over-all Menefee-Cliff House-Lewis sequence is a transgressive one; however, the main body of the Cliff House Sandstone in Chaco Canyon represents deposition during a near stand-still of the strandlinc. Rapid accumulation of marginal marine sediments was keeping pace with basin subsidence; minor regressions occurred when sediment accumulation exceeded subsidence and minor transgressions occurred when subsidence exceeded sediment accumulation.

Of significance in the understanding of the overall sedimentary environment for the sequence in question is the interpretation of the Menefee Formation. Beaumont, Shomaker and Kottlowski (1971) interpreted the upper coal-bearing part of the Menefee to be a result of "lagoonal or paludal" deposition occurring contemporaneously with Cliff House sand deposition and offshore Lewis shale deposition. Fluvial and deltaic conditions prevailed landward from the coastal lagoons. According to their (Beaumont, Shomaker and Kottlowski, 1971) stratidynamic model, there is a direct relationship between the rate of migration of a shoreline and the attendant environments of deposition. Thickest coal deposits occur during near still stands of the shoreline, wheras such deposits would not be developed during rapid shifts of the shoreline. Stagnant,

poorly drained swamps behind an island barrier would accumulate organic debris; such environments would be prohibitive to most faunal elements and thus explain the lack of any trace of faunal biogenic activity (body fossils and/or trace fossils) in upper Menefee deposits. Two characteristics of the Menefee are difficult to explain by the lagoonal model: 1) the absence of brackish-water fauna so characteristic of modern coastal lagoons, and 2) the presence of well-developed channel sandstone bodies in the upper part of the Menefee. Another significant feature is the presence of several fresh-water gastropod genera, but the total lack of brackish-water mollusks (especially bivalves) in the Cliff House fauna. Perhaps a model of delta deposition could better explain the Menefee Formation; however, more study is needed before such characteristics can be adequately explained.

The Cliff House Sandstone probably represents, for the most part, deposition in the lower to upper shoreface zone of a barrier island beach front. Lower, middle and upper shoreface environments are represented respectively by: 1) very fine-grained silty and clayey bioturbated sand (especially common in the middle slope-forming unit), 2) moderately low-angle trough cross-stratified fine-grained sand with less abundant, but well-developed, burrows (mostly *Ophiomorpha),* and 3) sub-parallel stratified, fine- to medium-grained sand containing locally abundant shell accumulations (assemblage 1). The coarsening upward trend is typical for such shoreface deposits. The lower shoreface facies may grade laterally and/or vertically into Lewis Shale type deposits; such transitional zones contain assemblage 2 accumulations. Shifting tidal channels, laterally adjacent to the barrier islands along depositional strike, are represented by the *Inoceramus-filled* troughs (assemblage 4).

The Cliff House lithosome overlies, is laterally adjacent to, and intertongues to the south with the Menefee lithosome. The main body of the Lewis lithosome lies to the north. Cliff House Sandstone deposition in the Chaco Canyon area ended when subsidence overcame sediment accumulation, the shoreline migrated to the south, and offshore marine sediments of the Lewis Shale accumulated above the Cliff House.

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APPENDIX

Macroinvertebrate Fossil Localities, This Study

1. SW 1/4 NE 1/4 sec. 26, T. 21 N., R. 10W., along lower cliff on north side of canyon approximately 1.6 km (1.0 mi) southeast of Chettro Kettle Ruins; thin fossiliferous lens, approx. 10 m (33 ft.) above base of lower cliff; Assemblage 1.

2. Approx. 100 m (330 ft.) east of locality 1; numerous large, profusely fossiliferous blocks at base of lower cliff (probably from calcite-cemented sandstone concretion zone near top of cliff); Assemblage 1.

3. Approx. 100 m (330 ft.) east of locality 1; fossiliferous lens (approx. 50-90 cm thick and 20-30 m wide), approx. 10 m (33 ft.) above base of lower cliff; Assemblage 1.

4. Approx. 120 m (400 ft.) east of locality 1; profusely fossiliferous, calcite-cemented sandstone concretion zone at top of lower cliff; Assemblage 1.

5. NW Y4 SW 1/4 sec. 18, T. 21 N., R. 10 W., along lower cliff on south side of canyon approx. 1.2 km (0.7 mi) southeast of Casa Rinconada Ruins; *Inoceramus* accumulations at base of lower cliff; Assemblage 4.

6. Approx. 50 m (80 ft) east of locality 5; profusely fossiliferous, calcite-cemented sandstone concretion zone at top of lower cliff; Assemblage 1.

7. SE 1/1 SW 1/4 NW 1/4 sec. 22, T. 21 N., R. 10W., north side of Gallo Wash Canyon, approx. 150 m (500 ft.) northeast of campground; thin (0.5 m) siltstone bed approx. 7 m (23 ft.) above top of lower cliff; abundant oyster fragments, shark teeth and bone debris; Assemblage 3.

8. SE 1/4 SE 1/4 sec. 12, T. 21 N., R. 11 W., north side of Chaco Canyon approx. 1.5 km (1.0 mi) southeast of Chettro Kettle Ruins; profusely fossiliferous, calcite-cemented sandstone concretion zone near top of lower cliff (near top of "stairway"); Assemblage 1.

9. NE 1/4 NW' SE 1/4 sec. 11, T. 21 N., R. 11 W., north side of canyon, approx. 0.3 km (0.25 mi) northwest of Kin Kletso Ruins; scattered, whole fossils in ferruginous sandstone bed approx. 5 m (16 ft.) above top of lower cliff; Assemblage 2.

10. SE Y4 NE 'A SW 1/4 sec. 1, T. 21 N., R. 11 W., southeast side of Clys Canyon; approx. 1.9 km (1.2 mi) northeast of Casa Chiquita Ruins along canyon exit road; profusely fossiliferous, calcite-cemented sandstone concretion zone at top of upper cliff; Assemblage 1.

11. NW 1/4 SW 1/4 NW 1/4 sec. 32, T. 21 N., R. 9 W., northeast side of Sheep Camp Canyon approx. 0.7 km (0.5 mi) northeast of Chaco Wash; scattered whole fossils in lightly ferruginous sandstone bed, 3 M (10 ft.) above top of lower cliff; Assemblage 2.

12. NW 1/4 NW 1/4 sec. 32, T. 21 N., R. 9 W., southeast side of Sheep Camp Canyon approx. 1.5 km (0.9 mi) northeast of Chaco Wash; profusely fossiliferous, calcite-cemented sandstone concretion near top of lower cliff; Assemblage 1.

13. SE A SW 'A NW 'A sec. 2, T. 20 N., R. 9 W., along north side of Chaco Canyon approx. 8.5 km (5.3 mi) east of national monument boundary; profusely fossiliferous, calcite-cemented sandstone concretion near top of lower cliff; Assemblage 1.

14. NE NW' SE sec. 14, T. 21 N., R. 11 W., west side of South Gap approx. 1.2 km (0.75 mi) southwest of Pueblo del Arroyo Ruins; scattered whole *Inoceramus* valves in ferruginous sandstone bed just above lower cliff; Assemblage 2.

15. NW 1/4 NW 'A sec. 20, T. 21 N., R. 10 W., south side of Chaco Canyon approx. 3 km (1.9 mi) southeast of Casa Rinconada Ruins (along road); extremely abundant *Inoceramus* accumulation at base of lower cliff; Assemblage 4.

16. Approx. 30 m (100 ft.) west of locality 15; profusely fossiliferous, calcite-cemented sandstone concretion zone near top of lower cliff; Assemblage 1.

17. Approx. 40 m (130 ft.) west of locality 15; thin siltstone bed approx. 3 m (10 ft.) above top of lower cliff containing abundant fragmented oysters, shark teeth and bone debris; Assemblage 3.

18. Approx. 200 m (650 ft.) west and southwest of locality 15, around point; *Inoceramus* accumulations at base of lower cliff; Assemblage 4.

19. NW 1/4 NW 1/4 NE'/ sec. 19, T. 21 N., R. 10W., on south side of Chaco Canyon approx. 2.1 km (1.3 mi) southeast of Casa Rinconada Ruins (along road); *Inoceramus* accumulations at base of lower cliff; Assemblage 4.

20. SW 1/4 NE 1/4 sec. 4, T. 21 N., R. 11 W., south side of

Chaco Canyon near junction of Chaco Wash, Escavada Wash and Chaco River at western boundary of national monument; *Inoceramus* accumulations at base of sandstone exposed just above wash; Assemblage 4.

21. SW '*A* NW 1/4 SW 1/4 sec. 24, T. 21 N., R. 11 W., along east side of South Gap and on southwest corner of South Mesa; approx. 0.7 km (0.4 mi) west of Tsin Kletzin Ruins; *Inoceramus* accumulations at base of upper cliff; Assemblage 4.

22. SE 1/4 NW'/ sec. 22, T. 21 N., R. 11 W., along west side of South Gap and southeastern corner of West Mesa; approx. 3.6 km (2.2 mi) southwest of Pueblo del Arroyo Ruins; *Inoceramus* accumulations at base of upper cliff; Assemblage 4.

Macroinvertebrate Fossil Localities of Vann (1931)

1. The vicinity of Chettro Kettle Ruins; 40 ft above base of lower cliff.

2. 1.2 mi east of Pueblo Bonito Ruins; 40 ft above base of lower cliff.

3. 2 mi east of Pueblo Bonito Ruins; 40 ft above base of lower cliff.

4. 3 mi east of Pueblo Bonito Ruins; 40 ft above base of lower cliff.

5. 1.2 mi west of Pueblo Bonito Ruins; 40 ft above base of lower cliff.

6. South side of Chaco Canyon, directly across from Chettro Kettle Ruins; approx. 30 ft above base of lower cliff.

7. Top of lower cliff behind Pueblo Bonito Ruins; approx. 100 ft above base of lower cliff.

8. North cliff at mouth of Escavada Wash; approx. 75 ft below top of upper cliff.

9. La Fajada Butte, at southern entrance to canyon; collections from talus slope.

10. 8.1 mi east of Pueblo Bonito; approx. 50 ft below top of upper cliff.

11. 8 mi east of Pueblo Bonito; south side of canyon; near base of lower cliff.