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THE CARLILE-NIOBRARA CONTACT AND LOWER NIOBRARA STRATA NEAR EL VADO, NEW MEXICO

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INTRODUCTION

The purpose of this paper is fourfold: 1) to describe the contact between beds of Carlile age and Niobrara age near El Vado, New Mexico; 2) to describe an unnamed, but distinctive unit of shale in the Niobrara-equivalent part of the Mancos Shale; 3) to correlate units in the El Vado section with those of adjacent areas; and 4) to illustrate fossils that were collected from the El Vado section.

The Mancos Shale exposures near El Vado, New Mexico are strategically located (Fig. 1) because they lie in a transition zone between areas characterized by the typical Great Plains Cretaceous stratigraphic sequence and by the classic intertongued sequence of Mancos Shale and Mesaverde Group to the west. Lamb (1973) discussed nomenclatural problems that have arisen because of the complex vertical and lateral distribution of Upper Cretaceous facies in the San Juan Basin. Stratigraphic nomenclature used in the El Vado area combines elements of that used in the Great Plains region with that used in the San Juan Basin. For example, Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Shale, all of which have formational status in the Great Plains, were designated by Dane (1948, 1960a) as members of the Mancos Shale in the eastern part of the basin in Rio Arriba County, New Mexico. Landis and Dane (1967), however, abandoned Carlile and Niobrara as member names in the Tierra Amarilla quadrangle because they believed that contacts between beds of Carlile age and Niobrara age cannot be precisely located in that area. Instead, they (Landis and Dane) described two lithologically distinctive units in the Niobrara-equivalent part of the section which they named Cooper Arroyo Sandstone Member and El Vado Sandstone Member of the Mancos Shale. They did not mention lithologic equivalents to these units in the Great Plains region.

In the section measured near El Vado (Fig. 2) the Cooper Arroyo Sandstone and El Vado Sandstone are separated by about 62 m (203 ft) of calcareous mudstone and shale that is lithologically quite similar to parts of the Smoky Hill Shale Member of the Niobrara Formation in eastern Colorado. This unit will be formally named as a member of the Mancos Shale in a subsequent publication (King, in preparation), but in this paper it is informally designated "lower Smoky Hill interval". The "lower Smoky Hill interval" can be correlated on the basis of the macroinvertebrate fossils it contains with units described by Scott and Cobban (1964) in the Niobrara reference section at Pueblo, Colorado, and on the basis of stratigraphic position with units in the southern and western parts of the San Juan Basin.

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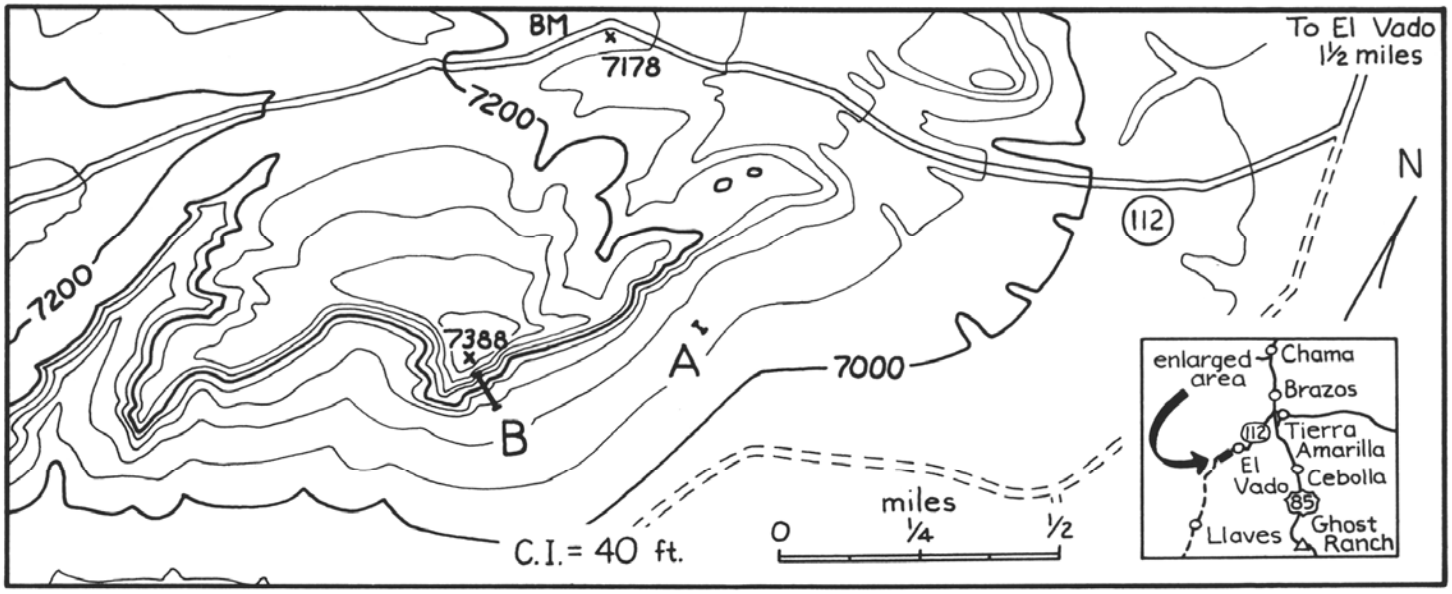

Figure 1. Index map showing location of measured section near El Vado, New Mexico. Unnamed shale unit beneath Cooper Arroyo Sandstone, and lower part of Cooper Arroyo measured at A; upper part of Cooper Arroyo and lower Smoky Hill interval measured at B. Topography from Boulder Lake quadrangle and Tierra Amarilla quadrangle 15-minute topographic maps.

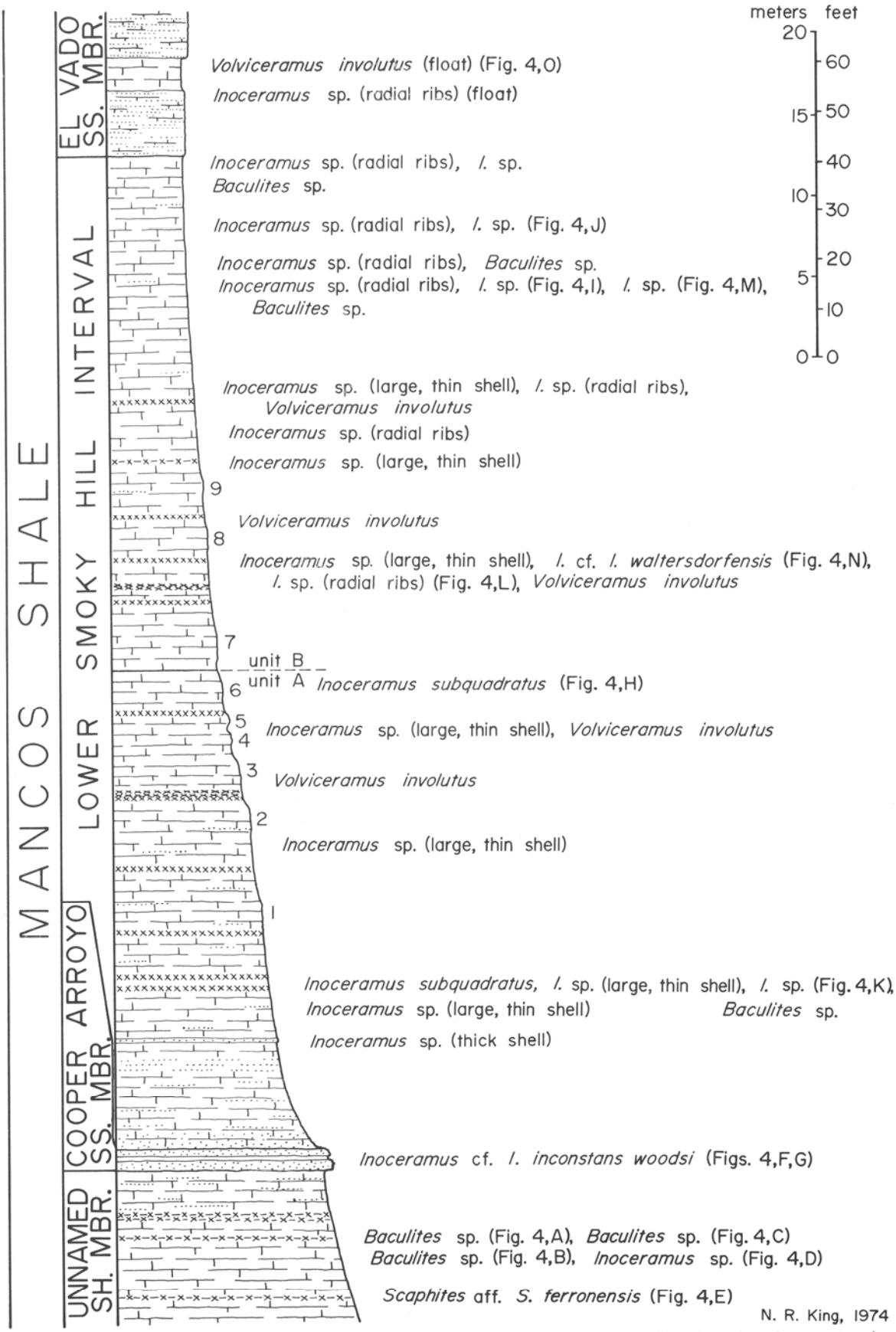

Figure 2. Graphic representation of beds exposed at site of measured section. Numbers 1 to 9 opposite the weathering profile are keyed to numbered resistant beds labeled on the outcrop photograph of the lower Smoky Hill interval (Fig. 6). Fossils illustrated in this paper are labeled with appropriate figure numbers.

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THE CARLILE-NIOBRARA CONTACT

The contact between beds of Carlile age and Niobrara age in the Great Plains region and in the San Juan Basin has been the subject of considerable interest to stratigraphers. The contact is disconformable in western Kansas (Hattin, 1962) and in parts of eastern Colorado (Johnson, 1930; Dane, *et al.,* 1937; Scott and Cobban, 1964). Kauffman (1967) and Kauffman and others (1969) referred to both conformable and unconformable contacts in Colorado. The author (King, 1972) concluded that the Carlile-Niobrara contact is conformable and gradational at several localities in southern Colorado (e.g. in Huerfano Park and near Canon City, Pagosa Springs, and Trinidad) and in northeastern New Mexico (near Springer and Las Vegas).

Much has been written about the Carlile-Niobrara contact in the San Juan Basin. Dane (1960b) presented evidence that the contact corresponds to a regional unconformity. Oil-bearing basal Niobrara sandstone bodies ("Tocito sandstone") have been interpreted as transgressive sandstones deposited on, or a short distance above, the Carlile-Niobrara unconformity (Lamb, 1968; McCubbin, 1969; Molenaar, 1973). However, not all workers agree that such a regional unconformity exists (e.g. Campbell, 1971 and 1973). Nevertheless, data from many areas in and adjacent to the San Juan Basin indicate that unconformities, regional or not, are especially common near the Carlile-Niobrara boundary.

In those parts of the southern Great Plains region where the sequence is conformable and gradational, the contact is located at the base of the lowest bed of hard, resistant, fine-grained limestone in a series of such beds. These limestone beds, which are separated by mostly thinner beds of calcareous shale, constitute the Fort Hays Limestone Member of the Niobrara Formation. Individual bedding units, including the basal bed, in the Fort Hays are time-parallel (King, 1973), hence this contact is everywhere the same age. As used subsequently in this paper, the term "Carlile-Niobrara boundary" refers to the horizon that separates beds of Carlile age from those of Niobrara age, as objectively defined by the lithologic contact specified above.

To the author's knowledge, the Carlile-Niobrara boundary as thus defined does not correspond to the upper or lower limit of the vertical range of any macroinvertebrate fossil. Consequently, in areas where the distinctive limestone facies of the Fort Hays is not developed, the exact position of the Carlile-Niobrara boundary cannot be located. However, vertical distribution of inoceramid bivalves can be used to locate the interval of strata in which the time boundary is represented. In areas of conformable sequence in the Fort Hays lithotope the top of the range of *Inoceramus* cf. *I. perplexus* Whitfield normally lies less than a meter beneath the contact; the range of I. *incertus* J imbo (as emended by Nagao and Matumaoto, 1940) spans the boundary; the base of the range of *I. lusatiae* Andert invariably lies less than a meter above the contact. Rock units and ranges of inoceramid bivalves mentioned in this paper are shown in Figure 3.

Fort Hays lithologies are not present near El Vado, consequently in that area the position of the Carlile-Niobrara boundary must be approximated using faunal data. In previously published reports it has been claimed that the boundary lies at an as yet undetermined level in the shale that underlies the Cooper Arroyo Sandstone (Landis and Dane, 1967) or that it corresponds to an unconformity at the base of the Cooper Arroyo Sandstone (Dane, 1960b; Lamb, 1968). Dane (1960b) hypothesized that the unconformity increases in magnitude toward the north, truncating a greater amount of section in that direction. At the exposures near El Vado which were examined during this investigation the basal contact of the Cooper Arroyo Sandstone seems to be a surface along which bedding-plane faulting has occurred. Slabs of sandstone are broken away from the base of the main body of the Cooper Arroyo and have been incorporated into a chaotic zone in the upper few centimeters of the underlying shale. Some of these slabs are not entirely detached from the base of the member, but extend downward into the shale at an oblique angle to bedding, with the upper end of the slab still in contact with the sandstone above. Fractured edges of these slabs are readily observable, so it is clear that they are not simply sand-filled borings or burrow structures. If physical evidence for unconformity at the base of the Cooper Arroyo Sandstone ever existed it has probably been obliterated by the faulting.

The upper 1.5 m (4.9 ft) of shale subjacent to the Cooper Arroyo contains numerous, but inconspicuous, laminae of fine-grained sandstone. Such laminae are not present lower in the unit. Although the contact is not obviously gradational, occurrence of those laminae in the upper part of the shale suggests that there was a gradual change to the high-energy conditions which caused introduction of the relatively coarse-grained sediment of the Cooper Arroyo Sandstone.

Faunal data, however, strongly suggest that the basal contact of the sandstone corresponds to an unconformity. *Scaphites* aff *S. ferronensis* Cobban (Fig. 4, E) was collected from shale 7.85 m (25.75 ft) below the contact. William A. Cobban (personal communication) stated that the specimen probably represents an undescribed species, but nevertheless indicates a late Carlile age. Shale beds closer to the contact contain only indeterminate baculitid cephalopods (Figs. 4, A, B, C) and inoceramid bivalves (Fig. 4, D), hence the exact age of the uppermost part of the shale has not been determined. The Cooper Arroyo Sandstone contains *Inoceramus* cf. I. *inconstans woods!* Fiege (Figs. 4, F, G), which is characteristic of the "shale and limestone unit" of the Fort Hays Limestone in eastern Colorado.' Landis and Dane (1967, p. 8) reported

1. The "shale and limestone unit" was assigned to the basal Smoky Hill Shale by Scott and Cobban (1964), who nevertheless stated (p. 10) that the lowest beds of Smoky Hill aspect occur in the overlying "lower shale unit." Leroy and Schieltz (1958) considered the "shale and limestone unit" to be a transition interval between the Fort Hays and Smoky Hill. The author (King, 1973) assigned the "shale and limestone unit" to the Fort Hays, and cited evidence that the upper contact of the unit is disconformable.

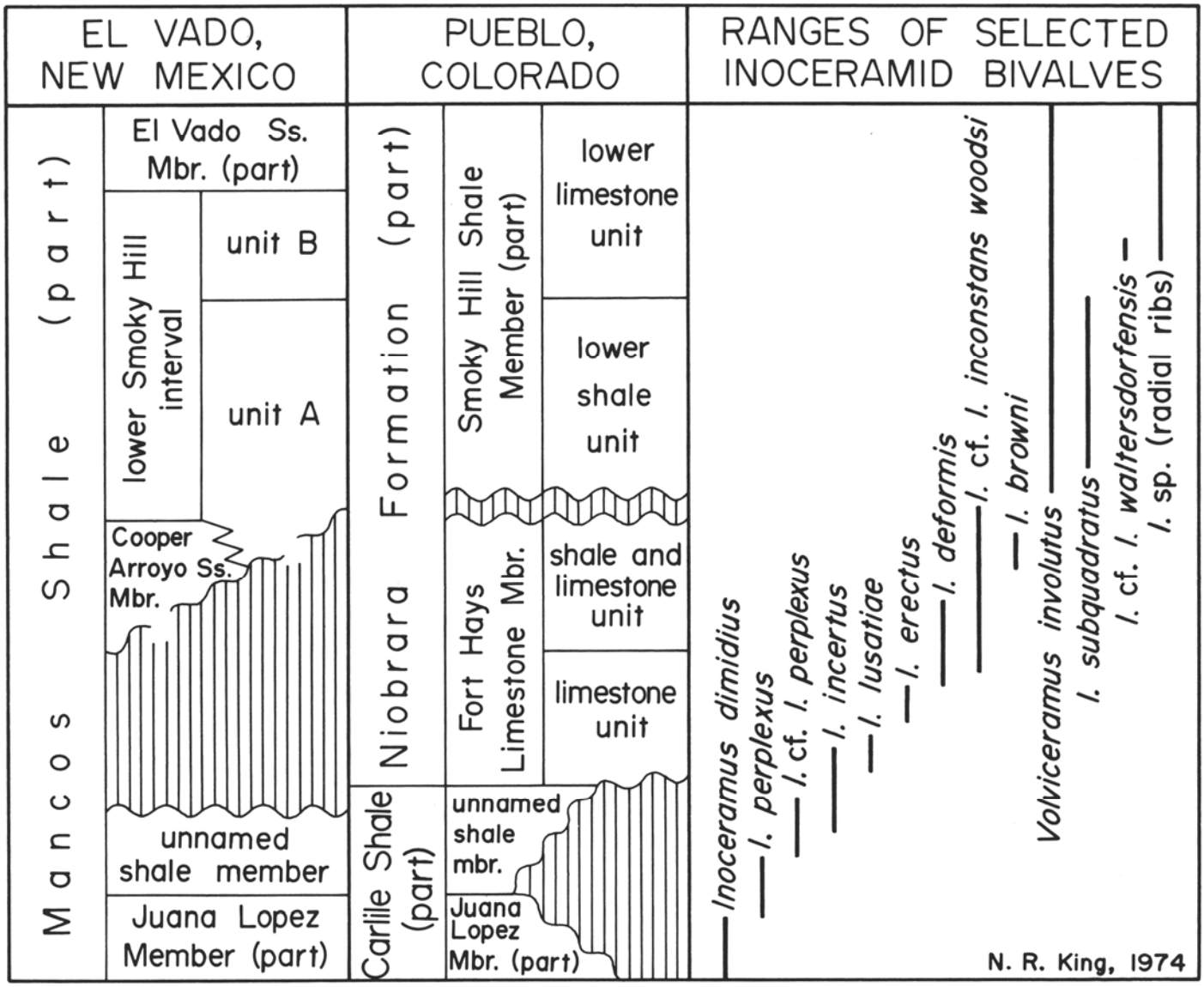

Figure 3. Correlation of upper Carlile and lower Niobrara rock units near El Vado, New Mexico and Pueblo, Colorado. Ranges shown for inoceramid bivalves are composite ranges for the two areas. Ranges of Inoceramus dimidius *White and* I. perplexus *Whitfield from Kauffman and others (1969).*

Figure 4. Fossils collected from upper Carlile and lower Niobrara strata exposed near El Vado, New Mexico. Figures are natural size except as indicated. **A,** *impression of crushed specimen of smooth species of* Baculites, *4 m below base of Cooper Arroyo Sandstone (UNM no. 74-1-4, A);* **B,** *crushed baculitid having lateral ornament similar to that of* Baculites asper *Morton, 5.15 m below base of Cooper Arroyo Sandstone (UNM no. 74-1-4, B);* **C,** *latex rubber cast of crushed baculitid having lateral ornament similar to that of* Baculites codyensis *Reeside (UNM no. 74-1-4, C);* **D,** *articulated valves of juvenile(?)* Inoceramus *sp., 4.4 m below base of Cooper Arroyo Sandstone (UNM no. 74-1-4, D);* **E,** Scaphites *aff.* S. ferronensis *Cobban, 7.85 m below base of Cooper Arroyo Sandstone (UNM no. 74-1-4, E);* **F,** *latex rubber cast of right valve of* Inoceramus *cf.* I. inconstans woodsi *Fiege, Cooper Arroyo Sandstone, 0.6 mi. NNE of 6932 elevation mark at north end of west arm of El Vado Reservoir on Boulder Lake quadrangle 15-minute topographic map (UNM no. 74-1-4, F);* **G,** *latex rubber cast of right valve of* Inoceramus *cf.* I. inconstans woodsi *Fiege, collected by E. R. Landis from Cooper Arroyo Sandstone in NE ¼ of sec. 3, T. 26 N., R. 3 E., X ½ (USGS no. D4154, UNM no. 74-1-4, G);* **H,** *latex rubber cast of right valve of* Inoceramus subquadratus *Schlüter, near top of unit A, lower Smoky Hill interval (UNM no. 74-1-4, H);* **I,** *right valve of* Inoceramus *sp., 23.3 m above base of unit B, lower Smoky Hill interval (UNM no. 74-1-4, I);* **J,** *left valve of* Inoceramus *sp., 27.0 m above base of unit B, lower Smoky Hill interval (UNM no. 74-1-4, J);* **K,** *right valve of* Inoceramus *sp., 10.7 m above base of unit A, lower Smoky Hill interval (UNM no. 74-1-4, K);* **L,** *latex rubber cast of right valve of* Inoceramus *sp. (radial ribs), 6.3 m above base of unit B, lower Smoky Hill interval (UNM no. 74-1-4, L);* **M,** *latex rubber cast of left valve of* Inoceramus *sp., 22.4 m above base of unit B, lower Smoky Hill interval (UNM no. 74-1-4, M);* **N,** *left valve of* Inoceramus *cf.* I. waltersdorfensis *Andert, 6.3 m above base of unit B, lower Smoky Hill interval (UNM no. 74-1-4, N);* **O,** *latex rubber cast of both valves of* Volviceramus involutus *(Sowerby), float from El Vado Sandstone, X ½ (UNM no. 74-1-4, O).*

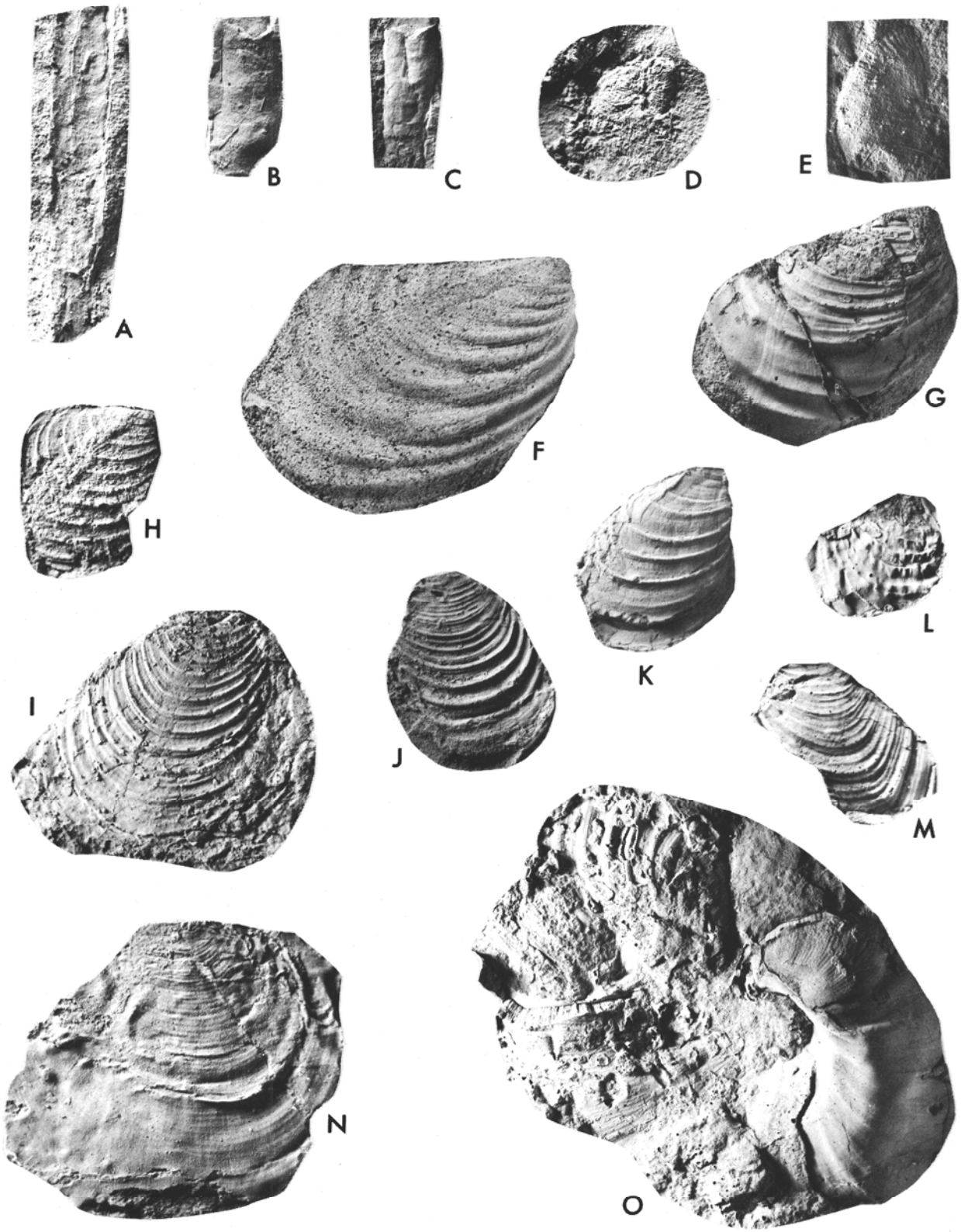

Figure 4.

that I. *erectus* Meek occurs in the Cooper Arroyo Sandstone in the type area, however the material that they collected (e.g. Fig. 4, G) is not typical of that species, and the zone of I. *erectus* seems to be absent at El Vado. *Inoceramus lusatiae* and associated species, and also typical I. *deformis* Meek are lacking, hence at least three inoceramid faunal zones in eastern Colorado are not present in the El Vado area. Beds beneath the contact are of late Carlile age, and the Cooper Arroyo Sandstone is of early, but not earliest, Niobrara age. Thus the boundary between beds of Carlile age and Niobrara age near El Vado is unconformable and corresponds to the contact between the Cooper Arroyo Sandstone and the underlying unnamed shale unit (Fig. 5).

At exposures to the north (Pagosa Springs area) and east (Springer and Las Vegas) the Carlile-Niobrara contact is conformable. But at Pagosa Springs there is an unconformity within the lower part of the Niobrara-equivalent Mancos Shale. The relatively thin Fort Hays interval is overlain by blocky, concretionary, highly calcareous mudstone that contains I. *erectus* in the concretions. This species is characteristic of the middle of the "limestone unit" of the Fort Hays Limestone in eastern Colorado. Resting directly on the concretionary mudstone are beds of highly calcareous shale and mudstone that contain I. *subquadratus* Schluter (Fig. 4, H), a species which occurs elsewhere (including near El Vado) in strata equivalent to the "lower shale unit" of the Smoky Hill Shale. Beds containing I. *deformis, I.* cf. I. *inconstans woodsi,* and the upper Fort Hays species I. *browni* Cragin are absent at Pagosa Springs. These data indicate that unconformities may occur in the San Juan Basin at levels near, but not exactly coincident with, the Carlile-Niobrara boundary. Indiscriminate use of the term "Carlile-Niobrara unconformity" is therefore risky because of the possibly erroneous implications inherent in such a designation.

The author (King, 1973) hypothesized that the unconformity at Pagosa Springs is continuous with one which locally truncates the Gallup Sandstone and associated units farther to the south and west in the San Juan Basin. Fossils collected from the Gallup and subjacent strata in the southern and northwestern parts of the basin *(Inoceramus* cf. *I. erectus* from the Gallup near Cabezon Peak, and I. *incertus* from just beneath the Gallup near Shiprock) indicate an early Niobrara age for the Gallup at those exposures. Thus Niobrara-age strata lie beneath the unconformity in other parts of the basin besides the Pagosa Springs area, and a greater interval of strata was truncated near El Vado than at some localities to the north, south, and west. In yet other areas, however, basal Niobrara sandstone bodies rest directly on the Juana Lopez Member of the Mancos Shale (Pentilla, 1964; Lamb, 1968; McCubbin, 1969), indicating an even greater amount of truncation.

LOWER SMOKY HILL INTERVAL

The lower Smoky Hill interval is dominated by olive gray to olive black, highly calcareous mudstone. Beds having the greatest carbonate content form especially steep, commonly vertical segments of the exposure where it is not covered by soil (Fig. 6). The mudstone is blocky where fresh, but upon weathering breaks into slabs and plates that are bounded by broadly curved surfaces. The lower 30.2 m (99.1 ft) of the lower Smoky Hill interval, referred to subsequently as unit A, consists almost entirely of the mudstone. Thin, commonly undulatory and discontinuous, laminae of olive gray, grayish orange, and moderate yellowish-brown, fine- to medium-grained, calcareous sandstone occur throughout unit A but are especially numerous near its base. In several zones the grayish rock is mottled with moderate yellowish-brown to dusky yellowish-brown coloration. The lower contact of unit A is gradational with the underlying Cooper Arroyo Sandstone, consequently the contact is inferred to be conformable.

A prominent sandy zone from 7.0 to 7.15 m (22.95 to 23.45 ft) above the base of Unit A contains fragments of a thick-shelled *Inoceramus.* The species is indeterminant, however, and it is uncertain whether this part of the section correlates with the uppermost Fort Hays Limestone or the basal Smoky Hill Shale. A flat, thin-shelled species of *Inoceramus* that is at least 25 cm in diameter occurs from 7.85 m (25.75

Figure 5. Outcrop of unnamed shale member and lower part of Cooper Arroyo Sandstone Member of Mancos Shale near El Vado, New Mexico.

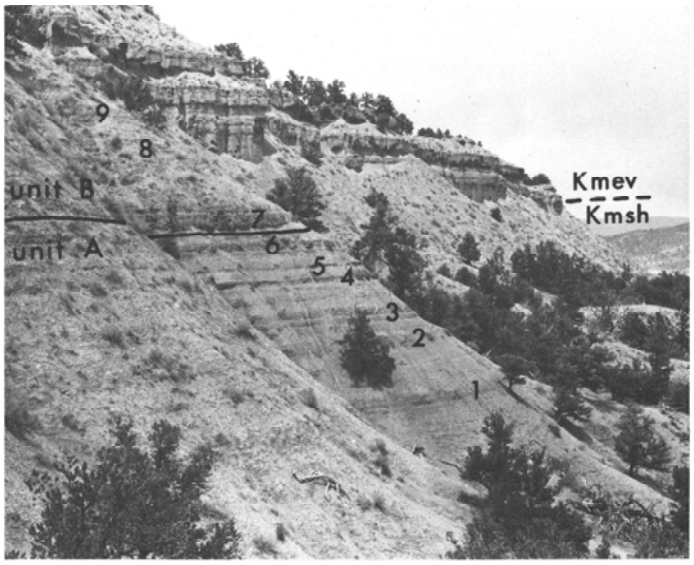

Figure 6. Outcrop of lower Smoky Hill interval of Mancos Shale (Kmsh) and lower part of El Vado Sandstone Member of Mancos Shale (Kmev) near El Vado, New Mexico. Numbered beds are keyed to graphic section (Fig. 2).

ft) above the base of the unit to the top. These and similar large, thin-shelled *Inoceramus* in the Smoky Hill Shale and equivalent part of the Mancos Shale are normally seen in outcrop as thin layers of prismatic calcite encrusted with small oysters. Most specimens consist of both valves in opposition. The shells are larger and thicker higher in the section, and probably more than one species is represented. None were successfully collected by me. Scott and Cobban (1964, p. 10) reported that a thin, flat *Inoceramus* having a diameter of at least 12 inches occurs in the "lower shale unit" of the Smoky Hill Shale at Pueblo, Colorado.

Inoceramus subquadratus (Fig. 4, H) occurs from 9.75 m (32 ft) above the Cooper Arroyo Sandstone to near the top of unit A. An unidentified species of *Inoceramus* (Fig. 4, K) that is possibly related to I. *subquadratus* was collected at 10.7 m (35.1 ft) above the base of the unit. The range of *Volviceramus involutus* (Sowerby) (Fig. 4, 0) in the El Vado area extends from 22.5 m (73.8 ft) above the Cooper Arroyo to the El Vado Sandstone. *Inoceramus subquadratus* occurs in the "lower shale" near Las Vegas, New Mexico, and *V. involutus* is common in the "lower shale" throughout eastern Colorado and northeastern New Mexico. Therefore I have correlated unit A with the "lower shale unit" of the Smoky Hill Shale.

The upper 31.8 m (104.3 ft) of the lower Smoky Hill interval, referred to subsequently as unit B, consists of interbedded olive gray to olive black, highly calcareous mudstone and moderate yellowish-brown to dusky yellowish-brown, laminated, commonly speckled, papery calcareous shale, as well as rock intermediate between those two types. Large, thin-shelled *Inoceramus* which are up to 80 cm in diameter, and *V. involutus* are common in the lower part of unit B. Several smaller species of *Inoceramus* also occur in the unit. *Inoceramus* cf. *I. waltersdorfensis* Andert (Fig. 4, N) is especially common in a narrow zone from about 6.1 to 6.6 m (20.0 to 21.65 ft) above the base of the unit. At least one radially-ribbed species (Fig. 4, L) extends from the same narrow zone into the overlying El Vado Sandstone Member. Scott and Cobban (1964, p. 11) reported that a radially-ribbed *Inoceramus,* referred to by them as a variant of I. *stantoni* Sokolow, occurs in the "lower limestone unit" of the Smoky Hill Shale at Pueblo, Colorado. The "lower limestone" also contains *V. involutus.* Therefore I have correlated unit B with the "lower limestone unit" of the Smoky Hill. Occurrence of *V. involutus* and radially-ribbed *Inoceramus* in the El Vado Sandstone (all specimens collected in float) suggests that at least a part of the El Vado also correlates with the "lower limestone."

Inoceramus cf. *I. waltersdorfensis* and additional, unidentified species of *Inoceramus* (Figs. 4, I, J, M) collected from unit B have not been reported from eastern Colorado or northeastern New Mexico.

Near Cabezon Peak the lower part of the El Vado Sandstone contains poorly-preserved inoceramids which resemble I. *stantoni* as pictured by Stanton (1899; as *I. acuteplicatus* Stanton). The Dalton Sandstone also contains *I. stantoni* (E. G. Kauffman, personal communication). Dane (1960a, p. 73) tentatively correlated the El Vado Sandstone (not named at that time) with the Dalton. The position of the "lower Smoky Hill interval" below the El Vado Sandstone but above the Carlile-Niobrara unconformity therefore indicates that the interval should be correlated with the Mulatto Tongue of the Mancos Shale in the southern and western parts of the San Juan Basin.

The El Vado Sandstone of the El Vado area was described by Landis and Dane (1967). Similar sandy beds occur in the middle Smoky Hill in the Plains of northeastern New Mexico and southeastern Colorado, but the relationship of these beds to the El Vado Sandstone has not been determined.

SUMMARY

The boundary between beds of Carlile age and Niobrara age in the El Vado area corresponds to an unconformity which may be regional in extent. The Cooper Arroyo Sandstone is correlative with the upper part of the Fort Hays Limestone of eastern Colorado, and the unnamed shale unit which underlies the Cooper Arroyo is correlative with the uppermost Carlile Shale. Beds subjacent to the presumed regional unconformity are not everywhere the same age, nor are beds which rest on the unconformity everywhere the same age.

The Cooper Arroyo Sandstone and El Vado Sandstone are separated by an interval of fine-grained, calcareous strata which resembles parts of the Smoky Hill Shale in eastern Colorado. Fossils of inoceramid bivalves contained in the interval indicate correlation with the "lower shale" and "lower limestone" units of the Smoky Hill. The lower Smoky Hill interval at El Vado is correlative to the south and west with the Mulatto Tongue of the Mancos Shale.

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