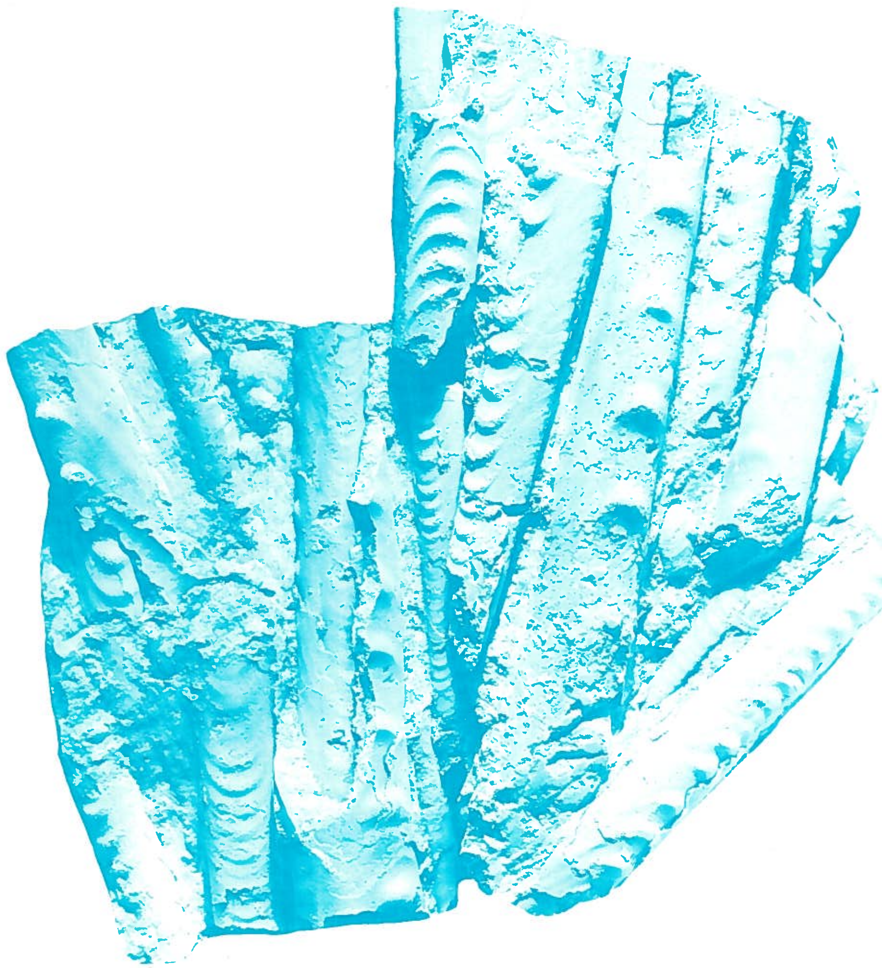
Stratigraphy of the Upper Cretaceous Niobrara Formation in the Raton basin, New Mexico

by Glenn R. Scott, William A. Cobban, and E. Allen Merewether



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U.S. Geological Survey, Denver, Colorado 80225

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Contents

Figures

Tables

Abstract

The Niobrara Formation in the Raton basin of northeastern New Mexico consists of the Fort Hays Limestone Member, about 20 ft thick, and the overlying Smoky Hill Shale Member, 800-900 ft thick. The Fort Hays Member is composed of seven to ten beds of light-gray-weathering, hard, dense limestone separated by soft, calcareous shale. A more varied lithology characterizes the Smoky Hill Member, which consists of four unnamed units. A 35-40 ft thick sequence of calcareous shale and shaly limestone, that forms the basal part of the Smoky Hill, is herein referred to as the shale and limestone unit. It is overlain by 95-125 ft of calcareous shale and minor shaly limestone, herein called the lower shale unit. These rocks are overlain by a sandy unit, 410-440 ft thick, most of which is moderately soft, shaly, very fine-grained sandstone that weathers yellowish brown to grayish orange. Parts of this unit contain calcareous concretions. The uppermost part of the Smoky Hill Member, herein referred to as the upper shale unit, is 265-295 ft thick and consists mostly of calcareous shale. The unit also includes at least 10 beds of orange-weathering argillaceous limestone, some beds of sandy shale, and limestone concretions. All contacts between the units of the Smoky Hill Member appear conformable, and the Smoky Hill rests conformably on the Fort Hays Member.

The Niobrara Formation was deposited in a marine environment and is moderately fossiliferous. Molluscan fossils are dominant. Inoceramids prevail; ammonites are scarce in the Fort Hays Limestone Member and in the lower two units of the Smoky Hill Shale Member. The molluscan fossils in the Raton basin indicate a late Turonian age for the Fort Hays Member and possibly a very late Turonian to early Campanian age for the Smoky Hill Member.

Geochemical data from pyrolysis assays of eight outcrop samples indicate that the Niobrara Formation in parts of the Raton basin contains potential source rocks for oil and gas. In some areas of the basin, the Niobrara is thermally mature and presumably has generated hydrocarbons.

Introduction

The purpose of this report is to present new information about the stratigraphy, fossils, and organic matter in the Upper Cretaceous Niobrara Formation in the Raton basin, New Mexico (Fig. 1). This study contributes stratigraphic sections and descriptions of all parts of the Niobrara, descriptions and illustrations of the marine molluscan fossils present, and a tabulation and appraisal of some constituent organic matter. The rock units and fossils of the Niobrara Formation in the Raton basin are correlated with those near Pueblo, Colorado, described earlier by Scott and Cobban (1964). The present report provides a biostratigraphic framework for future, more detailed investigations of the petrography, mineralogy, sedimentary structures, depositional environments, and other aspects of the Niobrara Formation.

The index fossils of the Niobrara are time-equivalents of fossils in other parts of the world and permit correlation of the Niobrara rocks with rocks elsewhere. Many of the fossil species are the same as those listed by Scott and Cobban (1964) for the Pueblo area. The remaining species, which typify some of the faunal zones of the Coniacian, Santonian, and Campanian Stages, have been found in other regions.

The discovery of gas in the upper chalk unit of the Smoky Hill Shale Member of the Niobrara Formation in the eastern part of the Denver basin in 1972 (Lockridge and Scholle, 1978) focused much attention on the formation. The upper chalk unit in the Denver basin is 20-50 ft thick and is regarded as a primary reservoir that has high porosity and low permeability; however, the permeability is enhanced by natural and induced fractures. Unfortunately, in northeastern New Mexico the upper chalk is almost entirely replaced by calcareous shale that contains orange-weathering limestone. In this region, the upper calcareous shale probably has little potential for the production of gas or oil, although it probably is a source rock for oil and gas in some areas.

Previous work

Previous investigations of the Niobrara Formation have been recently summarized by Hattin (1982, pp. 2-7) in his excellent treatise on the Smoky Hill Chalk Member of Kansas. The most comprehensive studies of the biostratigraphy concern the Pueblo area of southeastern Colorado (Scott and Cobban, 1964) and west-central Kansas (Frey, 1972; Hattin, 1982). In contrast to the work in these areas, little has been published about the Niobrara in the New Mexico part of the Raton basin. The mention of *Inoceramus deformis* Meek by Darton (1928, p. 271) in the Las Vegas area may be the only published record of a Niobrara fossil in northeastern New Mexico. Wood, Northrop and Griggs (1953) briefly described the Niobrara Formation in the Springer area, where they recognized a Fort Hays Limestone Member and a Smoky Hill Marl Member. They noted that the Smoky Hill Member consists of a lower calcareous shale unit, a middle sandy shale unit, and an upper calcareous shale unit. These authors mapped the Fort Hays Member separately, but they combined the Smoky Hill Member with the overlying Pierre Shale as a unit on their map.

Present study

While mapping the geology of the Raton and Springer 30' x 60' quadrangles in northeastern New Mexico (Fig. 1) in 1980-1982, Scott briefly studied the Niobrara Formation. His investigation included measuring and describing outcrop sections, collecting fossils, and establishing boundaries between stratigraphic units. No continuous section of the Niobrara Formation was found in the Raton—Springer area; scattered outcrops and the incomplete exposure of the units prevented the measurement of complete sections. Nevertheless, Scott measured many incomplete

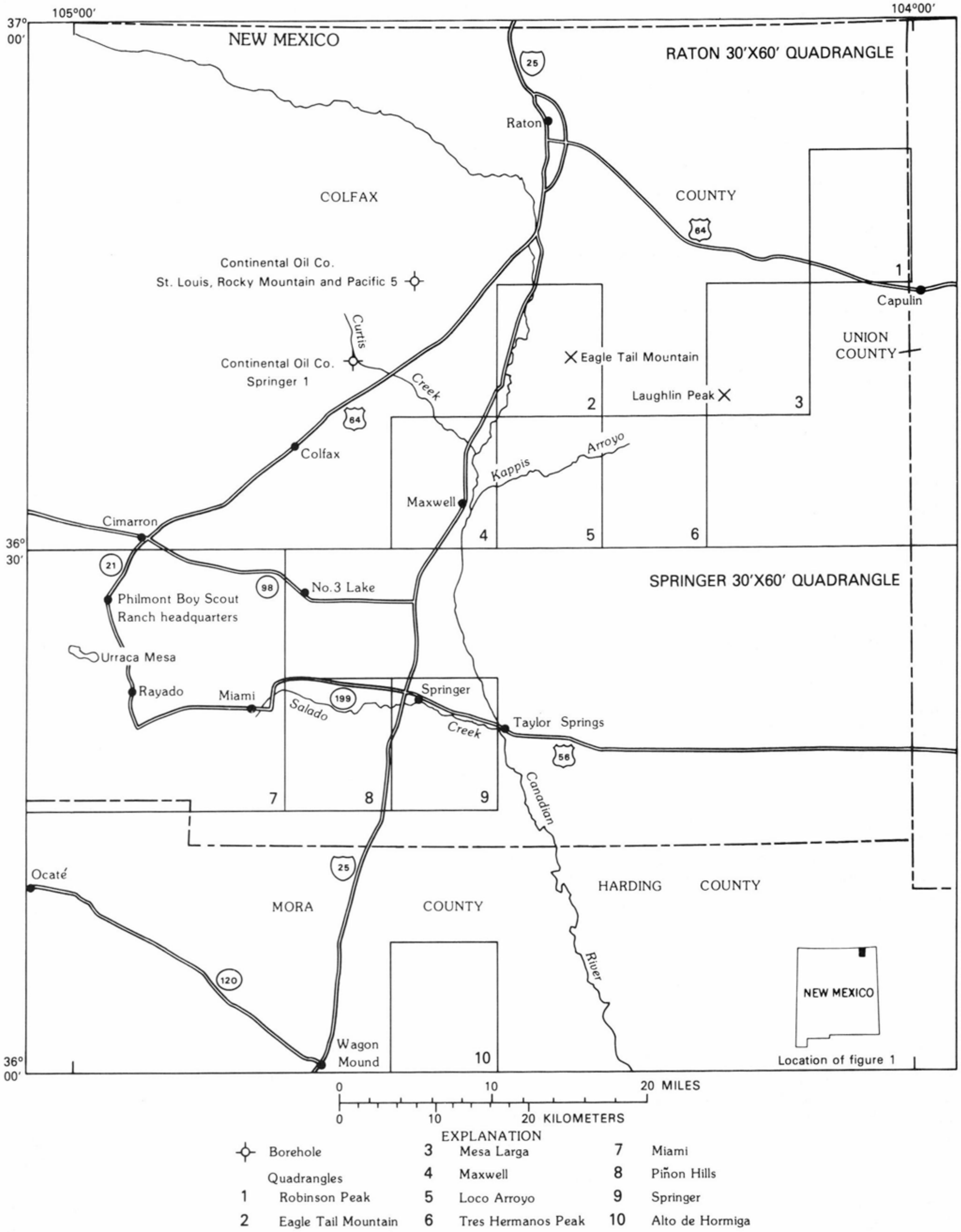


FIGURE 1—Index map showing locations of quadrangle maps and other features in the Raton basin, New Mexico, mentioned in the text.

sections of all the units. Because the Niobrara Formation of northeastern New Mexico had never been studied, little was known about the fossils in that area. Scott collected hundreds of fossils at most of the available sites. In the spring of 1984, all three authors and **R.** E. Burkholder of the U.S. Geological Survey collected additional fossils.

In studying the Niobrara, the Fort Hays Limestone Member was recognized as the lowest part and informal names were applied to four lithologically distinct units of the overlying Smoky Hill Shale Member. Underlying the Fort Hays Member is a calcareous shale member of the Carlile Shale; overlying the Smoky Hill Shale Member is the Pierre Shale. Because the lithologies of the upper part of the Niobrara and the lower part of the overlying Pierre Shale are gradational, the contact between the two formations has not previously been mapped. A boundary between calcareous beds of the Niobrara Formation and noncalcareous beds of the Pierre Shale was found during this study and was mapped as an approximate contact. The stratigraphic divisions of the Niobrara Formation described in this report are depicted on geologic maps of the Raton 30' x 60' quadrangle (G. R. Scott, U.S. Geological Survey, unpublished mapping) and the Springer 30' x 60' quadrangle (Scott, in press).

Acknowledgments

R. E. Burkholder photographed the fossils. These fossils have been assigned USNM catalog numbers, and are kept at the National Museum of Natural History, Washington, D.C. Other fossils collected in the course of this investigation have been assigned USGS Mesozoic locality numbers that have a **D** (Denver) prefix, and are in the reference collections of the U.S. Geological Survey at the Federal Center, Denver, Colorado.

Outcrops of the Niobrara Formation in northeastern New Mexico were sampled by Merewether in 1984 for an assessment of the oil and gas resources of the Raton basin. The organic composition of the samples was determined by T. A. Daws of the U.S. Geological Survey and reviewed by G. E. Claypool of the U.S. Geological Survey.

Stratigraphy

The Niobrara Formation in the Raton—Springer area of the Raton basin is of open-marine origin and consists of two members, the Fort Hays Limestone Member and the overlying Smoky Hill Shale Member. The Smoky Hill Member is composed of four lithologic units, in ascending order a shale and limestone unit, a lower shale unit, a sandy unit, and an upper shale unit (Table 1). Geophysical logs of these strata are shown in Figs. 2 and 3.

Each unit of the Niobrara Formation has a distinctive fauna of invertebrates. These fossils are listed in the stratigraphic sections and many of them are illustrated in Figs. 6, 9, and 12-15. Most specimens are not from the sites where strata were measured and de

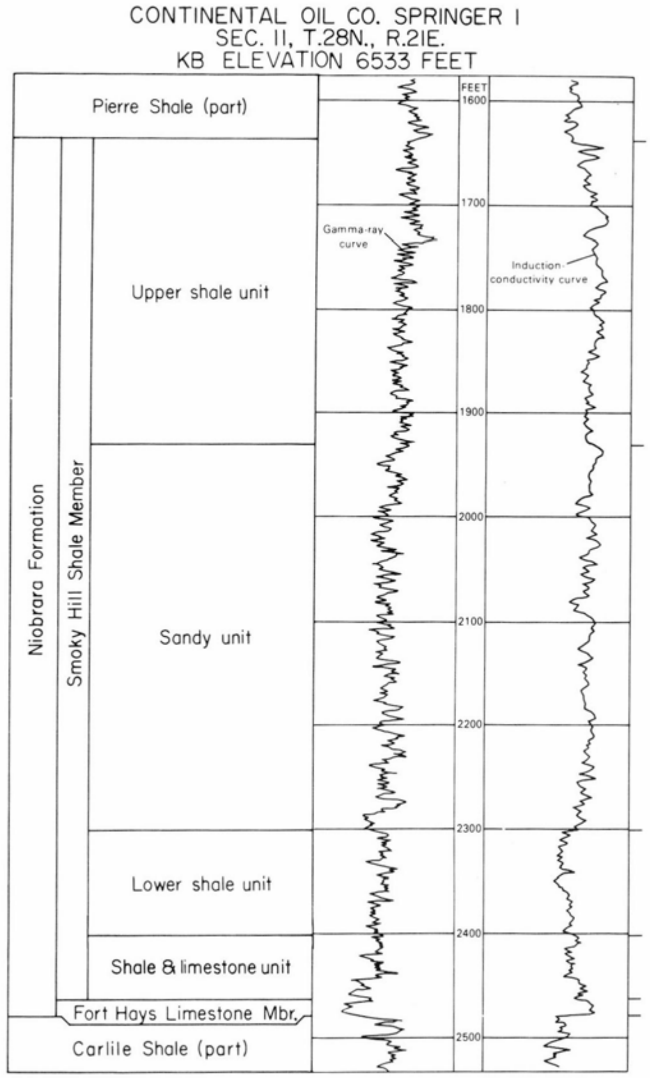


FIGURE 2—Representative electric log of the Niobrara Formation in Colfax County, New Mexico.

scribed; nevertheless, in the discussions of fossils and age, they have been tentatively assigned to beds of the stratigraphic sequence.

Fort Hays Limestone Member

The Fort Hays Limestone Member (Mudge, 1877, pp. 281-290; Williston, 1893, pp. 109, 110), of late Turonian age in the Raton basin, is a ledge-forming unit, and exposed sections range from 17 to 24 ft in thickness. This member is composed chiefly of hard, gray limestone and intervening, generally thicker, gray, calcareous shale. The Fort Hays generally forms a prominent bench, where the limestone weathers to flat fragments that hide the bedding. Individual beds can be distinguished and sections reliably measured only in the vertical faces of cliffs, quarries, and stream-cuts (Fig. 4). The member crops out from the northeastern corner of the Raton 30' x 60' quadrangle southward toward Capulin, then southwestward around the north side of Laughlin Peak, through Springer and

Subdivisions of the Niobrara Formation at Pueblo, Colo.

[Thicknesses are from measured sections]

Standard stages		Formation	Member and thickness	Unit and thickness		Fossils
Campanian	Lower	Niobrara	Smoky Hill Shale, 700 ft	Upper chalk, 8 ft		Inoceramus (Cordiceramus) simpsoni, Baculites sp. (smooth), Stramentum haworthi
				Upper chalky shale, 264 ft		Haresiceras placentiforme, Scaphites cf. S. hippocrepis, Baculites cf. B. haresi, Inoceramus sp.
					Concretionary subunit	Inoceramus (Platyceramus) platinus, Pseudoperna congesta
Santonian	Upper					Inoceramus (Cordiceramus) simpsoni, Inoceramus (Sphenoceramus) lundbreckensis, Ostrea sp., Baculites sp.
				Middle chalk, 28 ft		Inoceramus (Platyceramus) platinus, Pseudoperna congesta, Clioscaphites choteauensis, Baculites sp. (smooth)
				Middle shale, 283 ft	Concretionary subunit	Inoceramus sp. (quadrate species), Inoceramus (Platyceramus) platinus, Ostrea sp., Baculites sp. (smooth), Clioscaphites choteauensis
						Pseudoperna congesta
	Middle					Inoceramus (Platyceramus) platinus, Inoceramus (Cordiceramus) cordiformis, Clioscaphites vermiformis, Baculites codyensis
	Lower				Concretion subunit	Inoceramus (Platyceramus) platinus, Inoceramus (Cordiceramus) cordiformis, Ostrea sp., Anomia subquadrata, Lucina sp., Inoceramus (Cladoceramus) cf. undulatoplicatus, Clioscaphites saxitonianus, Baculites codyensis, Baculites asper, Texanites americanus, Stantonoceras pseudocostatum, Placenticeras planum
						Inoceramus (Platyceramus) platinus
					Sandy subunit	Pseudoperna congesta
						Inoceramus (Cladoceramus) undulatoplicatus
						Inoceramus (Cordiceramus) cordiformis
						Clioscaphites saxitonianus, Baculites codyensis
Coniacian	Upper					Inoceramus (Cladoceramus) undulatoplicatus, Inoceramus (Platyceramus) cf. stantoni, Scaphites depressus, Scaphites binneyi, Protexanites shoshonensis
	Middle			Lower limestone, 38 ft		Inoceramus (Volviceramus) grandis, Inoceramus (Magadiceramus) subquadratus, Pseudobaculites sp., Baculites codyensis, Baculites asper
						Neocrioceras sp.
						Inoceramus (Magadiceramus) subquadratus, Phlycticrioceras oregonense
						Inoceramus (Magadiceramus) subquadratus, Baculites codyensis
	Lower			Lower shale, 56 ft		Inoceramus (Volviceramus) involutus, Ostrea sp.
						Inoceramus (Platyceramus) stantoni
						Baculites asper, Baculites codyensis
						Inoceramus spp.
				Shale and limestone, 20 ft		Inoceramus (Volviceramus) involutus, Inoceramus (Cremnoceramus) deformis
						Inoceramus (Cremnoceramus) deformis
			Fort Hays Limestone, 40 ft			Inoceramus (Cremnoceramus) deformis
						Inoceramus (Cremnoceramus) erectus, Forresteria hobsoni
						Forresteria sp.
Turonian	Upper					Inoceramus longealatus

TABLE 1—Stratigraphy and fossils of the Niobrara Formation at Pueblo, Colorado, and in Raton basin, New Mexico.

Subdivisions of the Niobrara Formation in Raton Basin

[Thicknesses are from measured sections]

Formation	Member and thickness	Unit and thickness	Fossils
Niobrara	Smoky Hill Shale, 800-900 ft	Upper shale 265-295 ft	*Inoceramus (Endocostea) balticus, Inoceramus (Sphenoceramus) lundbreckensis, Scaphites hippocrepis II, Baculites haresi, Placenticeras* sp., *Eutrephoceras* sp.
			Inoceramus (Platyceramus) cycloides, Scaphites hippocrepis I. Placenticeras sp.
			Desmoscaphites bassleri, Baculites sp. (ribbed), *Haresiceras (Mancosiceras)* sp.
			Inoceramus (Cordiceramus) simpsoni, Inoceramus (Sphenoceramus) lundbreckensis, Baculites thomi, Desmoscaphites erdmanni
			Inoceramus (Cordiceramus) muelleri, Inoceramus (Endocostea) balticus, Inoceramus (Sphenoceramus) lundbreckensis, Baculites thomi, Scaphites leei I, Clioscaphites choteauensis, Desmoscaphites erdmanni, Texanites omeraensis, Reginaites leei
			Inoceramus (Platyceramus) platinus, Inoceramus (Platyceramus) cycloides, Inoceramus (Cladoceramus) sp., *Phelopteria linguaeformis, Pseudoperna congesta, Clioscaphites vermiformis, Glyptoxoceras novimexicanum*
			Inoceramus (Cordiceramus) muelleri, Inoceramus (Cordiceramus) bueltenensis
			Inoceramus (Platyceramus) platinus
		Sandstone 410-440 ft	*Inoceramus (Cordiceramus) cordiformis, Clioscaphites vermiformis, Baculites codyensis*
			Inoceramus (Cladoceramus) undulatoplicatus
			Inoceramus (Magadiceramus) subquadratus, Inoceramus (Cladoceramus) sp., *Neocrioceras* sp.
			Inoceramus (Volviceramus) grandis, Inoceramus (Magadiceramus) subquadratus, Protexanites shoshonensis, Phlycticrioceras oregonense, Baculites codyensis, Baculites asper
		Lower shale 95-125 ft	*Inoceramus (Magadiceramus) subquadratus, Inoceramus (Platyceramus) platinus, Pseudoperna congesta, Protexanites shoshonensis, Phlycticrioceras oregonense, Baculites* sp. (smooth)
			Inoceramus (Volviceramus) grandis, Pseudoperna congesta
			Inoceramus (Cremnoceramus) browni, Inoceramus (Cremnoceramus) schloenbachi
			Inoceramus (Cremnoceramus) deformis, Inoceramus (Cremnoceramus) schloenbachi
		Shale and limestone 35-40 ft	*Inoceramus (Cremnoceramus) rotundatus*
			Inoceramus sp., *Baculites* sp.
	Fort Hays Limestone, 17-24 ft		*Inoceramus longealatus, Inoceramus incertus, Inoceramus* aff. *labiatoidiformis, Inoceramus parvus, Prionocyclus guadratus, Baculites yokoyamai, Eutrephoceras* sp.

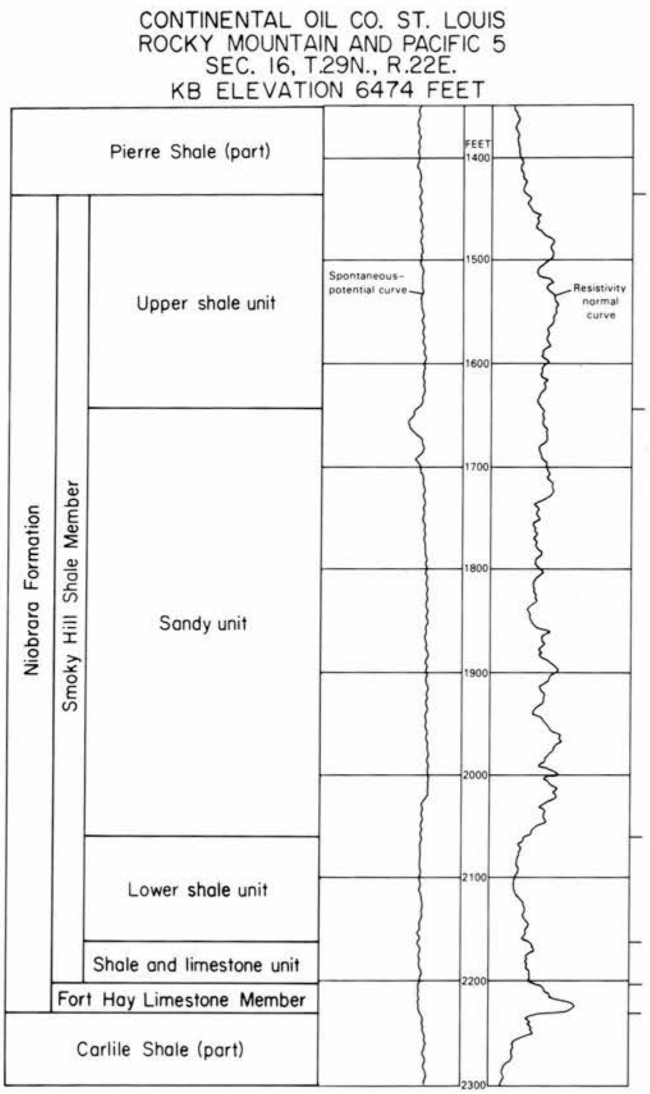


FIGURE 3—Representative gamma-ray and induction log of the Niobrara Formation in Colfax County, New Mexico.

FIGURE 4—Fort Hays Limestone Member of the Niobrara Formation along north bank of Salado Creek about 0.5 mi southwest of Springer, New Mexico.

Wagon Mound, then northwestward toward Ocaté (Fig. 5). The width of the outcrop belt varies from a few hundred feet to at least 12 mi.

The basal contact of the Fort Hays Limestone Member is at an abrupt change from dark-gray calcareous shale of the Carlile Shale upward into gray, resistant, massive limestone of the Fort Hays. This part of the Carlile is an unnamed, upper member; it is fossiliferous and contains some thin beds of gray, shaly limestone and several beds of yellowish-orange bentonite.

In the Raton and Springer 30' x 60' quadrangles, the Fort Hays consists of seven to ten layers of dense, gray limestone separated by gray, dark-gray, or olive-gray calcareous shale. A few beds of limestone near the top of the member are quite hard and flinty when fresh. Some of the limestone weathers shaly or platy. Limestone beds are 2-31 in. thick, but weather to thin, irregular, yellowish-gray layers or to chips. Locally, the limestone fills channels which had been scoured at least a foot deep. The shale that separates the limestone beds generally is soft and fissile to platy or blocky. Some unweathered, more calcareous shale layers resemble limestone. Undercutting of shale beds along streams commonly causes slumping of large limestone blocks. No bentonite beds were observed in the Fort Hays Limestone Member.

Fossils and age—The Fort Hays Limestone Member produced several species and subspecies of *Inoceramus,* two genera of ammonites, and a nautiloid. Only one faunal zone, that of the ammonite *Prionocyclus quadratus* Cobban, is present. The most fossiliferous outcrops of the member are slightly south of Springer in the SE1/4 sec. 33, T25N, R22E, Colfax County, and west of Wagon Mound in the SE1/4 sec. 26, T21N, R20E, Mora County.

Fossils characteristic of the Fort Hays Member in the Raton basin of New Mexico are *Inoceramus* aff. *labiatoidiformis* Tröger (of Keller, 1982), *I. incertus* Jimbo (Fig. 6g), *I. incertus mytiloidiformis* Trtiger (Fig. 61), *I. parvus* Tröger (Fig. 60, *I. longealatus* Tröger (Fig. 6a–e, i), and *Pycnodonte* sp. Rarer fossils include ostreids and the cephalopods *Baculites yokoyamai* Tokunaga and Shimizu (Fig. 12e), *Prionocyclus quadratus* Cobban (Fig. 6k), and *Eutrephoceras* sp. The age of this fauna is very late Turonian.

Inoceramus aff. labiatoidiformis Tröger (of Keller, 1982) is probably the most diagnostic fossil of the Fort Hays Member. This species is of moderate size, somewhat elongated, and fairly prosocline (Fig. 6h, j). The cross section along the growth axis has a very low convexity. The long, straight hinge line bounds a prominent posterior auricle that usually has a concave ventral margin. Ornament is variable but tends to fall into three growth patterns. Ornament on the beak and umbo consists of fairly evenly spaced concentric folds that follow a somewhat subcircular course. This is followed by a narrower band of closely spaced growth lines, and, in turn, by more widely spaced irregular growth rugae that are elongated along the growth axis. There are many variations of this general form. Some specimens have short auricles with only slightly concave posteroventral margins. The area of evenly spaced concentric folds on the early part of the shell may vary greatly, and the band of closely spaced

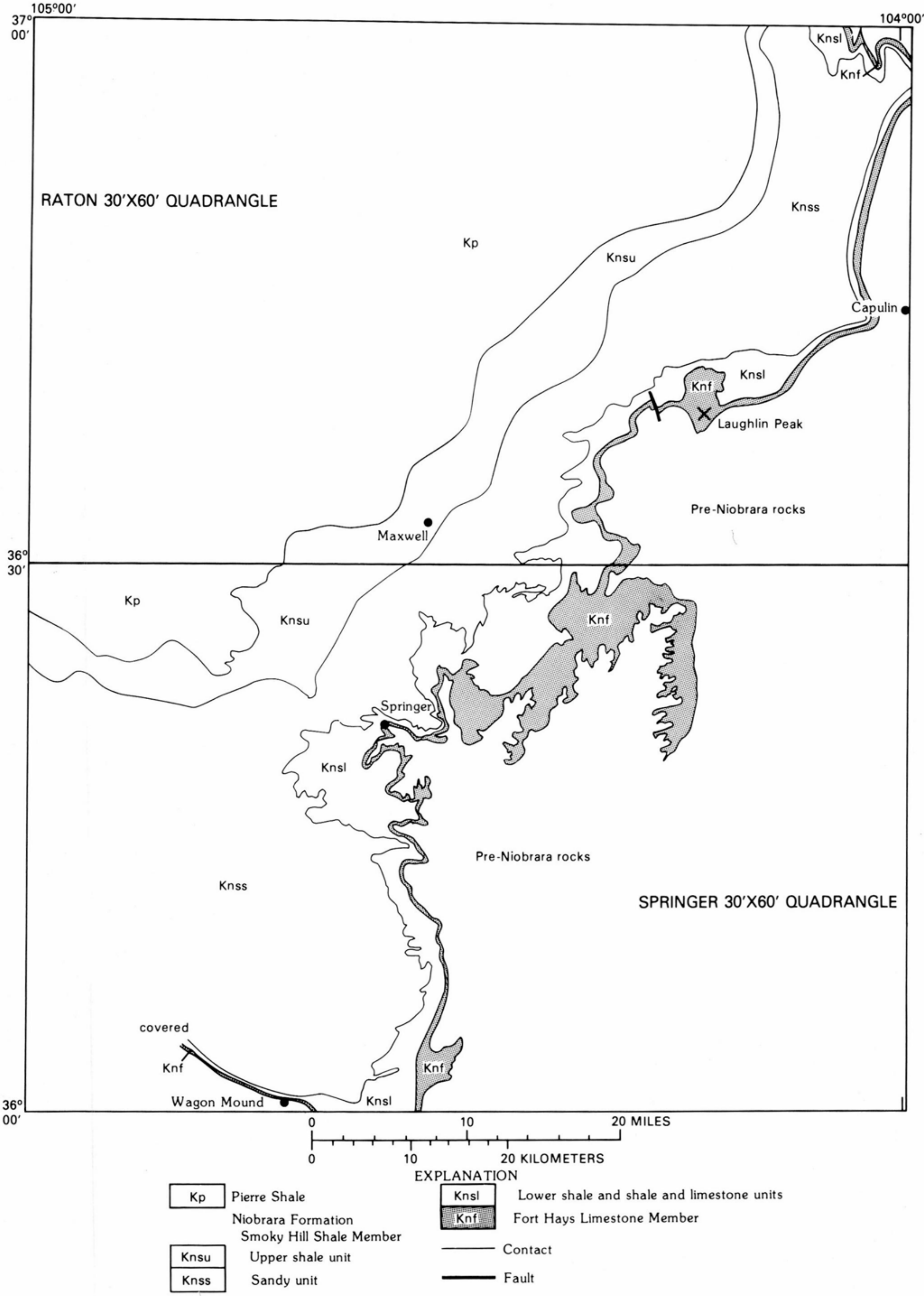
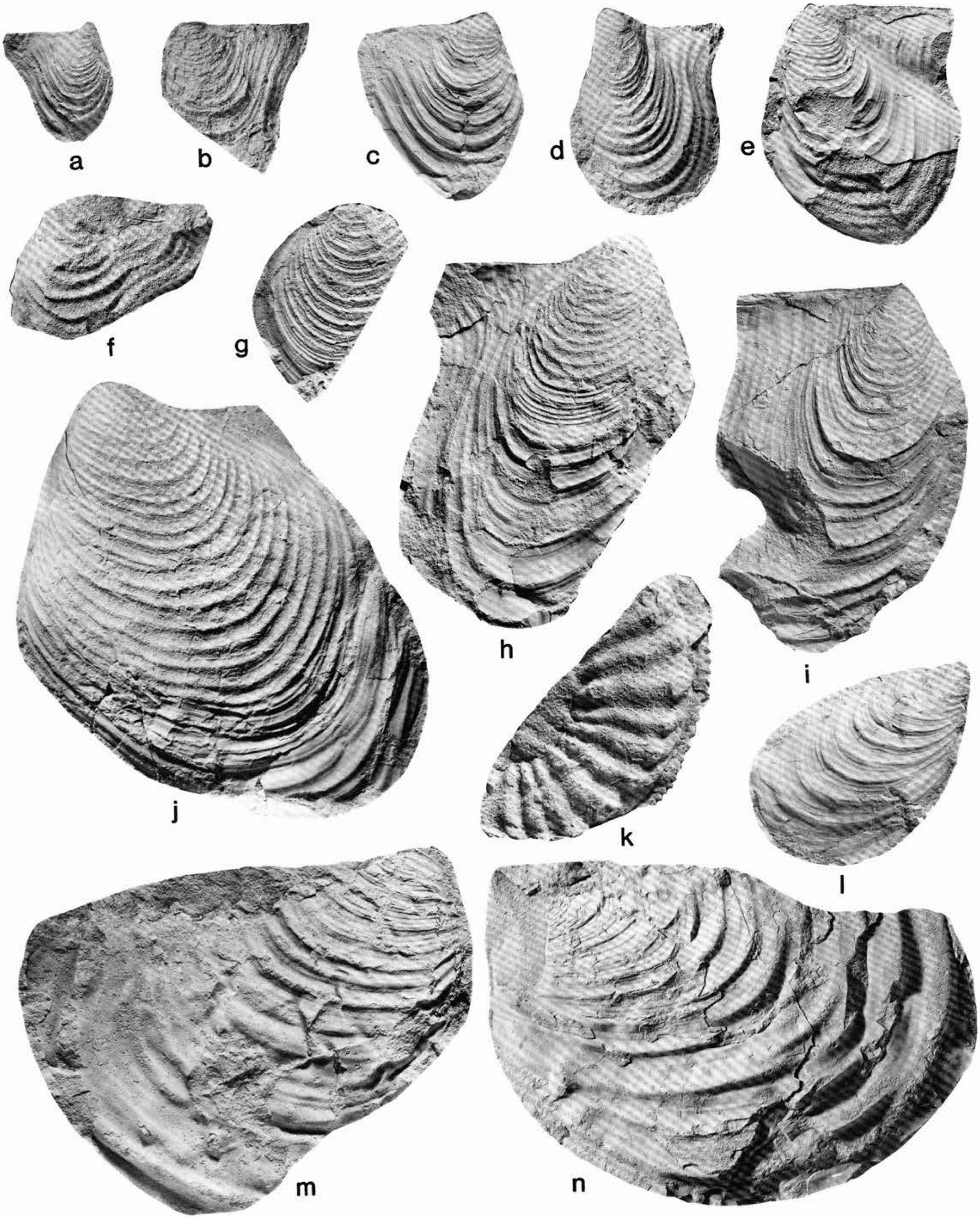


FIGURE 5—Generalized geologic map showing outcrop area of Niobrara Formation in Raton and Springer 30′ x 60′ quadrangles.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growth lines may be poorly developed or absent. This Fort Hays species shows considerable resemblance to a specimen from the upper Turonian of Germany that was assigned to *Inoceramus labiatoidiformis* Tröger by Keller (1982, pl. 5, fig. 5). However, Keller's specimen has a much shorter auricle. The holotype of *I. labiatoidiformis* Tröger (1967, pl. 10, fig. 5) is more prosocline and has more regular growth rugae. A specimen from the upper Turonian of Romania, that Pauliuc (1968, pl. 4, fig. la, b) assigned to *I. labiatus opalensis* Böse forma *elongata* Seitz may be the same as the Fort Hays species.

Other Fort Hays inoceramids include very alate specimens that seem referable to *I. vancouverensis parvus* Tröger (1967, p. 92, pl. 9, figs. 1-5, pl. 10, fig. 3) and *I. vancouverensis longealatus* Tröger (1967, p. 95, pl. 10, fig. 2) described from the upper Turonian of Germany. The more coarsely ornamented specimens from the Fort Hays (Fig. 60 are here referred to as *I. parvus* Tröger, and the more finely ornamented specimens (Fig. 6a-e, i) are referred to as *I. longealatus* Tröger.

Inoceramids with regular concentric folds separated by one to three growth lines also occur in the Fort Hays Member. Specimens with a subcircular outline (Fig. 6g, j) seem referable to *I. incertus* limbo (1894, p. 43, pl. 8, fig. 7), as emended by Nagao and Matsumoto (1940, p. 10) and recently treated again by Matsumoto and Noda (1983). More elongate specimens (Fig. 61) seem referable to *I. incertus mytiloidiformis* Tröger, a form described from the upper Turonian of Germany as *I. fiegei mytiloidiformis* by Tröger (1967, p. 108, pl. 11, fig. 4, pl. 13, figs. 16, 18) and recently illustrated from the upper Turonian of Japan as *Mytiloides* sp. aff. *mytiloidiformis* (Tröger) by Matsumoto and Noda (1983, fig. 5).

Smoky Hill Shale Member

The Smoky Hill Shale Member (Cragin, 1896, pp. 51-52), of late Turonian, Coniacian, Santonian, and early Campanian age in the Raton basin, is about 800-900 ft thick in the Raton-Springer area. It consists of shale, sandstone, and many thin beds of limestone as well as very thin beds of bentonite. The Smoky Hill crops out in a belt 4-20 mi wide (Fig. 5) that extends from the northeast corner of the Raton 30' x 60' quadrangle (Scott, unpublished mapping) southwestward to Maxwell and covers most of the western half of the Springer 30' x 60' quadrangle (Scott, in press). This member is divided into four units, which are informally named (ascending) the shale and limestone unit, the lower shale unit, the sandy unit, and the upper shale unit (Table 1). The sandy unit and several orange-limestone beds in the upper shale unit form low scarps.

Shale and limestone unit

The shale and limestone unit of latest Turonian and early Coniacian age is 35-40 ft thick and consists of limestone and gray, soft, calcareous shale. Most of the limestone beds are less resistant to weathering and are thinner than those of the Fort Hays. This unit is transitional between the Fort Hays and the typically fissile shale of the Smoky Hill Shale Member. The shale and limestone unit forms part of a gentle slope between the Fort Hays Limestone and the sandy unit of the Smoky Hill Member. It crops out poorly as rock-strewn gentle slopes; individual beds are identifiable only on steep slopes, such as in the railroad cut in the NE1/4NW[1]/4 sec. 4, T24N, R22E (Fig. 7).

The unit is not completely exposed at any single locality in the area, although 15 beds of limestone similar to those in the Fort Hays were measured in the railroad cut shown in Fig. 7. The limestone beds are gray and massive, and yellowish gray and shaly where weathered. Most of the beds are more clayey and weather more rapidly than those in the Fort Hays. Individual limestone beds range in thickness from 2 to 26 in. and average about 71/2 in. The shale in the unit is gray, calcareous, hard, and blocky. Weathered shale is yellowish gray and soft. The average thickness of the shale layers is 24 in. Bentonite beds were observed in the upper part of the unit.

Fossils and age-The shale and limestone unit is meagerly fossiliferous and contains only fragments of inoceramids, oysters, and *Baculites.* A few fragments of small inoceramids similar to those in the Fort Hays Member were collected from the lower part of the unit in a railroad cut in the NW1/4 sec. 4, T24N, R22E (USGS D12514). *Inoceramus (Cremnoceramus) rotundatus* Fiege was found near the top of the unit at locality D12525 in

FIGURE 7—Shale and limestone unit of Smoky Hill Shale Member of the Niobrara Formation in a railroad cut of Atchison, Topeka, and Santa Fe Railroad, less than 0.5 mi southwest of Springer, New Mexico.

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FIGURE 6—Inoceramid bivalves mostly from the Fort Hays Limestone Member of the Niobrara Formation. **a–e, i,** *Inoceramus longealatus* Tröger, hypotypes USNM 388255–388260 from a bed of limestone in the upper part of the Fort Hays Limestone Member at USGS Mesozoic locality D12522 in NW¼SE¼ sec. 26, T21 N, R20E, Colfax County, New Mexico. **f,** *Inoceramus parvus* Tröger, hypotype USNM 388261 from the same locality. **g,** *Inoceramus incertus* Jimbo, hypotype USNM 388262 from the same locality. **h, j,** *Inoceramus* aff. *labiatoidiformis* Tröger (of Keller, 1982), figured specimens USNM 388264 and 388263 from the same locality. **k,** *Prionocyclus quadratus* Cobban, hypotype USNM 388265 from the same locality. **l,** *Inoceramus incertus mytiloidiformis* Tröger, hypotype USNM 388266 from the same locality. **m, n,** *Inoceramus (Cremnoceramus) schloenbachi* Böhm, hypotypes USNM 388267 and 388268 from the same locality. All figures are natural size.

the SE1/4 sec. 26, T21N, R22E (Fig. 12b). These fossils indicate a very late Turonian to early Coniacian age.

A measured section of all but the upper part of the shale and limestone unit is included in section 1 of the Fort Hays Limestone Member; another partial section is included with descriptions of the lower shale unit. Three additional sections of the shale and limestone unit are given in sections 10-12.

Lower shale unit

The lower shale unit, of middle and late Coniacian age, is 95-125 ft thick and composed of shale and platy limestone. The lower part of this sequence resembles the gray, calcareous shale and limestone in both the Fort Hays Member and the shale and limestone unit of the Smoky Hill Member. The upper part is similar to the dark-gray shale typical of the Smoky Hill. Outcrops of the unit generally form a slope between the underlying beds of hard limestone and the overlying resistant sandy unit. The best outcrops are on steep slopes, in streamcuts, and in roadcuts, such as those on the south side of New Mexico Highway 199 at USGS locality D12512 in the NW1/4NE1/4NW1/4 sec. 33, T25N, R22E, Colfax County (Fig. 8). Some beds of the hard, shaly limestone form minor ledges on steeper slopes.

This unit is composed of dark-gray to black homogeneous shale and dark-gray limestone. In the lower part of the unit, the shale and limestone are in paired beds 4-5 in. thick; a succession of these pairs in the unit is many feet thick. The limestone beds are platy and weather white. The shale beds weather to soft, brittle flakes. Limestone layers are more plentiful and more platy in the upper part of the unit. Where well-exposed in a roadcut, e.g. at USGS locality D11375 in the SE1/4NE1/4SE1/4 sec. 9, T24N, R19E, Colfax County, plates of limestone more than 3 ft^2 and only 1/4 in. thick can be split from the upper layers of limestone. The unit also contains several beds of bentonite as much as 9 in. thick.

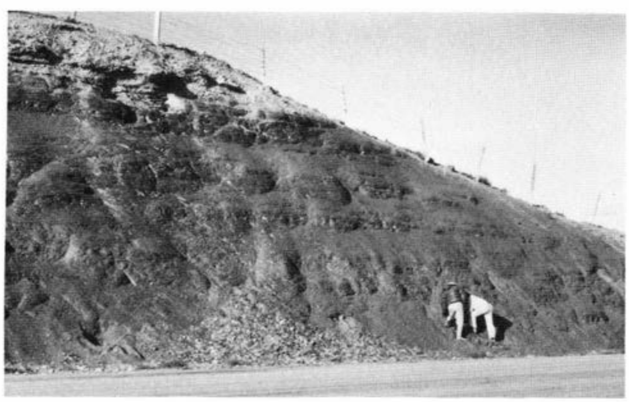


FIGURE 8—Lower shale unit of Smoky Hill Shale Member of the Niobrara Formation exposed along State Highway 199 about 0.5 mi west of Springer, New Mexico. Scott and Merewether collecting a large specimen of *Inoceramus browni* Cragin.

Fossils and age—Inoceramids characterize four faunal zones recognized in the lower shale unit. *Inoceramus (Cremnoceramus) deformis* Meek was collected at a single locality, an excavated outcrop where the lower shale unit has been baked by a lamprophyre dike, in the center of the 5E1/4 sec. 30, T28N, R25E, Colfax County (USGS D11966). That species probably came from the lowest part of the unit. *Inoceramus (Cremnoceramus) schloenbachi* Bohm also was collected at this locality (Fig. 6n). A thick-shelled *Inoceramus* with a diameter of about 12 in. was also found in the lower part of the unit at USGS locality D12512 in the NW1/4NE1/4NW1/4 sec. 33, T25N, R22E, Colfax County. It may represent *Inoceramus (Cremnoceramus) browni* Cragin. With it was *I. (Cremnoceramus) schloenbachi* (Fig. 6m). A rudist was found about 50 ft above the base of the unit.

Inoceramus (Volviceramus) grandis (Conrad) (Fig. 9i) is found in the upper part of the lower shale unit and extends upward into the overlying sandy unit. These specimens are heavily overgrown by oysters *(Pseudoperna congesta)* and have abundant borings interpreted as due to cirripeds. The upper part of the lower shale unit is the lowest part of the zone of *Inoceramus (Magadiceramus) subquadratus* Schlüter. Associated with it are *I. (Platyceramus) platinus* Logan?, *Pseudoperna congesta* (Conrad), *Baculites* sp. (smooth), *Phlycticrioceras oregonense* Reeside, *Protexanites shoshonensis* (Meek), and fish teeth and bones. At one of the most prolific localities, USGS D11375 in a road-cut in the SE1/4NE1/4SE1/4 sec. 9, T24N, R19E, *Protexanites shoshonensis, Inoceramus (Magadiceramus) subquadratus* , and smooth baculites were found a few feet below the top of the unit in chalky limestone.

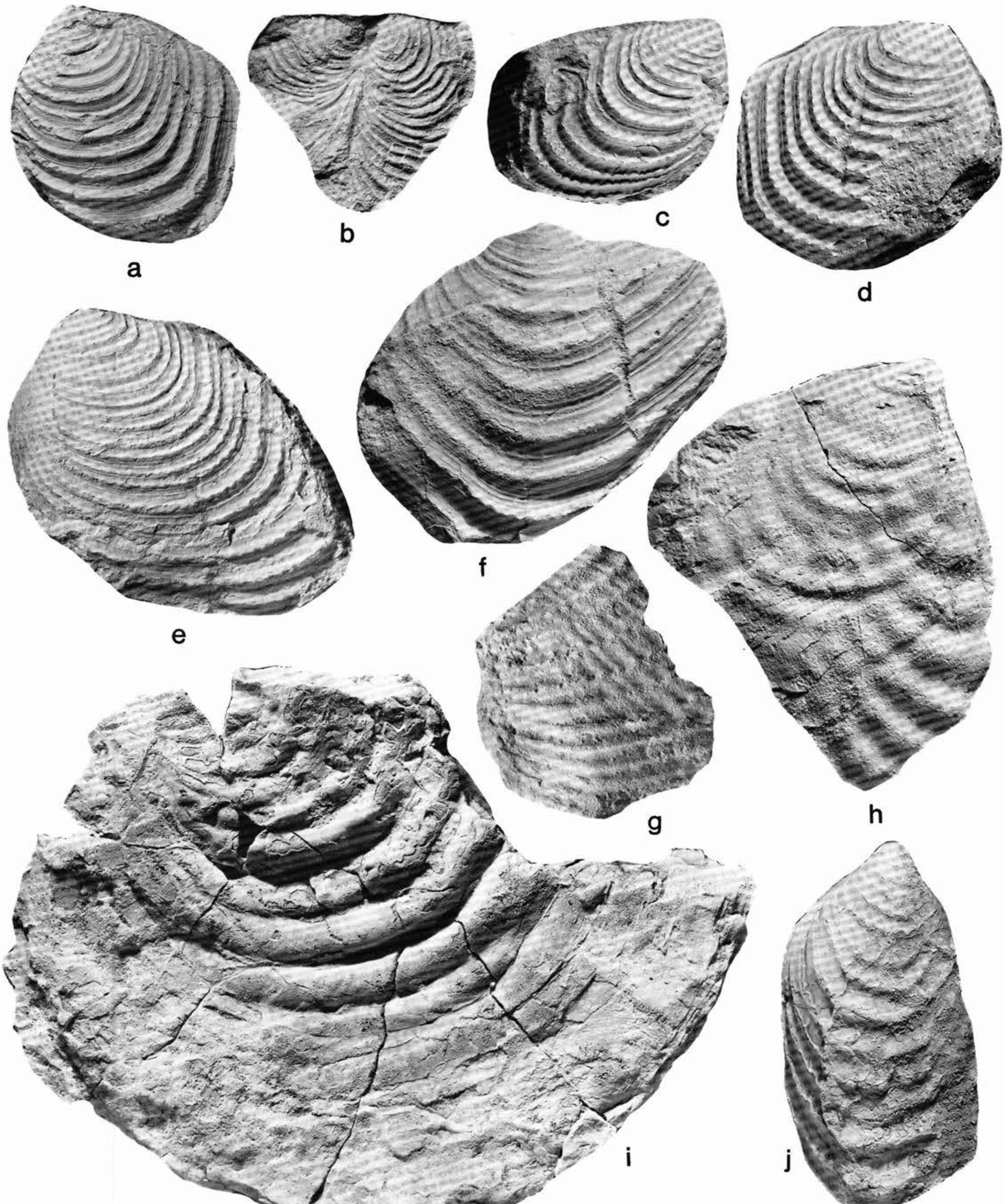
The lower shale unit is considered to be Coniacian in age. According to Kennedy (1984, p. 154), the ammonite *Phlycticrioceras* is late Coniacian in age. According to Seitz (1970), who investigated *Inoceramus subquadratus,* that inoceramid first appears in lower Coniacian rocks and becomes abundant in the upper Coniacian.

One complete section and a partial, faulted section, measured by Scott, are included in the measured sections.

Sandy unit

The sandy unit, of late Coniacian to early middle Santonian age (Table 1), is 410-440 ft thick and consists

FIGURE 9—Inoceramid bivalves from the Smoky Hill Shale Member of the Niobrara Formation. **a, b,** *Inoceramus (Magadiceramus) subquadratus subquadratus* Schlüter, hypotypes USNM 388269 and 388270 from limestone concretions in the lower part of the sandy unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11377 in NW¼SW¼ sec. 36, T24N, R21E, Colfax County, New Mexico. **c, f,** *Inoceramus (Magadiceramus) subquadratus crenelatus* Seitz, hypotypes USNM 388271–388274 from the same locality. **g,** *Inoceramus (Magadiceramus) subquadratus complicatus* Heine, hypotype USNM 388275 from a thin bed of sandstone in the sandy unit of the Smoky Hill Shale Member along Highway 193 at USGS Mesozoic locality D9781 in SW¼ sec. 33, T29N, R26E, Colfax County, New Mexico. **h,** *Inoceramus (Cladoceramus) undulatoplicatus* Roemer, hypotype USNM 388276 from the upper part of the sandy unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11304 in SW¼NE¼ sec. 31, T27N, R23E, Colfax County, New Mexico. **i,** *Inoceramus (Volviceramus) grandis* (Conrad), hypotype USNM 388277 from the upper part of the lower shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11732 in SE¼NW¼ sec. 16, T26N, R24E, Colfax County, New Mexico. **j,** *Inoceramus (Magadiceramus)* aff. *soukupi* Macak, figured specimen USNM 388278 from the same locality as a, b. All figures are natural size.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of shaly sandstone. The unit crops out in a broad band of gently dipping, shaly sandstone beds that trend southwestward across the Raton–Springer area (Fig. 5). It commonly forms a bench about 300 ft above the floors of adjoining valleys. The sandy beds are well exposed where gullies are cut into the bench. Elsewhere, the surface of the bench and adjoining slope are littered with sandstone chips 2-3 in. in diameter (Fig. 10).

The sandy unit is composed of dark-gray, yellowish-brown, or moderately yellowish-brown, irregularly bedded, fine-grained, well-sorted, quartzose sandstone that generally is in a matrix of dark shale. The unit locally weathers yellowish brown, moderately yellowish brown, or grayish orange. Thin, hard plates and lenses of the sandstone contain trails and impressions of trace fossils. Most of the sandy plates are less than 1/2 in. thick; however, the unit contains some calcarenite lenses as much as 4 in. thick and several feet in diameter. Most thick lenses are fossiliferous. Gray, fossiliferous limestone concretions about 8 in. in diameter occur 65 ft above the base of the sandy unit. A 15 ft thick layer of soft, dark-gray shale lies at least 40 ft below the top of the unit. This shale is the only non-sandy part of the unit. Another concentration of gray limestone concretions, which are as much as 20 in. in diameter and 9 in. thick, occurs within the upper few feet of the unit. These concretions contain brown calcite and white barite. The lithology of the sandy unit is so uniform that a stratigraphic section is not very informative. Sections 13 and 14 provide information about the relationship of the sandy unit to the underlying shale.

Fossils and age—The sandy unit of the Smoky Hill Shale Member is characterized by four inoceramid zones. *Inoceramus (Volviceramus) grandis* (Conrad) is in the basal part, which is about 10 ft thick, as well as in the underlying lower shale unit. *Inoceramus (Magadiceramus) subquadratus* (Schlüter) is also in both units. It is accompanied by *Protexanites shoshonensis* (Meek), *Baculites codyensis* Reeside, *B. asper* Morton, and *Phlycticrioceras oregonense* Reeside. Some excellent specimens of *I. (Magadiceramus) subquadratus* and subspecies were collected from limestone concretions 65 ft above the base of the sandy unit at USGS locality D11377 in the NW1/4SW1/4 sec. 36, T24N, R21E, Colfax County (Fig. 9a–g). The types of this species came from the Austin Chalk of Texas (Schluter, 1887, p. 43). The species also occurs in Germany, where Seitz (1970, pp. 17-38) assigned it to the subgenus *Magadiceramus* and recognized the subspecies *subquadratus subquadratus* Schluter, *subquadratus crenelatus* (new), *subquadratus crenistriatus* (Roemer) Heinz, and *subquadratus complicatus* Heine. The specimens from Colfax County represent the nominate subspecies and the subspecies *crenelatus* and *complicatus.*

FIGURE 10—Upper part of sandy unit of Smoky Hill Shale Member of the Niobrara Formation in a railroad cut slightly above USGS D11307 in the SE¼ sec. 26, T30N, R25E, Colfax County, New Mexico. This sequence of sandy shale and thin beds of very fine-grained sandstone is about 6 ft thick. Excellent specimens of *Baculites codyensis* Reeside (Fig. 13f) were obtained from this locality.

The lower middle part of the sandy unit, about 120 ft above the base, contains *Neocrioceras* in association with *Inoceramus (Magadiceramus) subquadratus* and *I. (Cladoceramus)* sp. The 15 ft thick shale about 40 ft below the top of the sandy unit contains *Inoceramus (Cladoceramus) undulatoplicatus* Roemer (Fig. 9h). This species was collected from the bed of the Canadian River in the SW1/4NE1/4 sec. 31, T27N, R23E, Colfax County (USGS D11304), and was also observed in the center of the NE1/4NW1/4 sec. 2, T26N, R23E, Colfax County.

The uppermost inoceramid zone is that of *Inoceramus (Cordiceramus) cordiformis* Sowerby (Fig. 12c), which was collected together with *Baculites codyensis* Reeside and *Clioscaphites vermiformis* (Meek and Hayden), from an orange, calcareous sandstone near the top of the unit in the center NE1/4 sec. 29, T27N, R23E, Colfax County (USGS D11603).

Upper shale unit

The upper shale unit of the Smoky Hill Shale Member, of middle Santonian to early Campanian age, is composed mainly of calcareous shale, but contains some sandy shale and many thin beds of limestone. The unit is 265-295 ft thick and forms a broad belt that extends from the northeastern part of the Raton 30' x 60' quadrangle southwestward through Maxwell and the southern part of the Philmont Boy Scout Ranch (Figs. 1, 5). The most complete sections of the upper shale unit are exposed at two places on the eastern and southern sides of Urraca Mesa (Fig. 1). Our section was measured in the SE1/4 sec. 7, T25N, R19E, where about 350 ft of the sandy unit and overlying upper shale unit are exposed (Fig. 11). The upper shale unit contains seven beds of ridge-forming, fossiliferous, orange limestone (see measured section 15). Elsewhere, the unit is less resistant and does not form ridges; however, scattered small outcrops of the orange-weathering limestone are locally visible on aerial photographs.

The upper shale unit consists of gray and olive-gray, sandy to silty, calcareous shale that is flaky, platy, and fissile. It probably contains as many as 10 beds of limestone and sparse beds of hard sandstone. The lowest part of the unit is characterized by an orange, earthy-weathering, sandy limestone and chalk 3-6 ft thick. A layer of sandy limestone concretions, 4-6 in. in diameter and containing crystalline barite, is present in the lower part of the orange limestone. Another layer of larger elliptical concretions containing fragments of thick shells of *Inoceramus (Platycer-*

FIGURE 11—Upper shale unit of Smoky Hill Shale Member of the Niobrara Formation exposed on the east side of Urraca Mesa about 8 mi south of Cimarron, Colfax County, New Mexico. Cliffs along skyline are Tertiary basalt.

amus) platinus Logan lies in the upper part of the limestone.

Most limestone beds in the upper shale unit have an average thickness of almost 12 in. They are gray, dense, and hard, and some are sandy. All beds weather orange and some weather platy. Others do not split along bedding and are so hard that they fracture conchoidally. Extraction of fossils is difficult except after prolonged weathering. Other limestone beds are platy and split readily where only slightly weathered. Orange septarian calcareous concretions were seen at one place.

In the upper part of the upper shale unit (probably in the interval of *Desmoscaphites bassleri* to *Scaphites hippocrepis)* there are, in addition to beds of orange-weathering limestone, several horizons of limestone concretions. A section of the shale interval that contains these concretion beds was measured along Curtis Creek in the NW1/4SW1/4NW1/4 sec. 6, T27N, R23E, Colfax County, and is shown in measured section 18.

Three stratigraphic sections of the upper shale unit, measured by Scott, are given in the measured sections. A complete section of the unit is not available; however, these sections are representative of the lithology of the unit.

Fossils and age—Eight faunal zones are recognized in the upper shale unit. The lowest zone, which occurs in the lowest part of the unit, contains *Inoceramus (Platyceramus) platinus* Logan (Fig. 12i). Fragments of this thick-shelled species are abundant in the lower, orange, earthy limestone and in the overlying gray, calcareous shale. These beds are well exposed in the cut of an abandoned railroad in the SW1/4NE1/4SE1/4 sec. 26, T3ON, R25E, Colfax County. *Baculites codyensis is* a common associated ammonite. Inoceramids slightly higher in the unit seem assignable to *Inoceramus muelleri germanicus* Heinz and *I. bueltenensis* Seitz.

The next faunal zone above *I. platinus* is that of *Clioscaphites vermiformis* (Meek and Hayden). This ammonite ranges through at least 200 ft of strata and can be collected from at least six outcropping limestone beds on the east side of Urraca Mesa (Fig. 1). It is associated with *Baculites codyensis, Glyptoxoceras novimexicanum* (Reeside) (Fig. 14a), *Inoceramus (Platyceramus) platinus* Logan, *I. (Cladoceramus)* sp., *I. (Platyceramus) cycloides* Wegner, *Pseudoperna congesta* (Conrad), and *Phelopteria linguaeformis* (Evans and Shumard).

The third faunal zone above the base of the unit is that of *Clioscaphites choteauensis* Cobban, which was tentatively recognized at three places in orange-weathering limestone beds 10-12 in. thick. Associated fossils include *Inoceramus (Sphenoceramus) lundbreckensis* (McLearn), *Inoceramus brancoiformis* Seitz?, *Pseudoperna congesta,* and *Baculites* sp. (smooth).

In the third faunal zone, a mixed assemblage was found in the uppermost orange-weathering limestone bed, which is about 10 in. thick, in the outcrop on the east side of Urraca Mesa in the SW1/4SE1/4 sec. 7, T25N, R19E, Colfax County, (USGS D11425). It consists of fossils usually found in two discrete faunal zones and includes ammonites *Clioscaphites choteauensis, Desmoscaphites erdmanni* Cobban, *Scaphites leei* I Reeside, *Baculites thomi* Reeside, *Texanites omeraensis* (Reeside), and *Reginaites leei* (Reeside), and inoceramids *Inoceramus (Cordiceramus) muelleri* Petrascheck, *I. (Endocostea) balticus* Bohm (Fig. 12h), and *I. (Sphenoceramus) lundbreckensis* (McLearn). The Roman numeral I after *S. leei* refers to the earliest of three forms of the species (Cobban, 1969).

The fourth faunal zone, that of *Desmoscaphites erdmanni,* also contains *Baculites thomi, Inoceramus (Sphenoceramus) lundbreckensis,* and *Inoceramus (Endocostea) simpsoni* Meek. The best collection of fossils of this zone is from a gray limestone bed in gray, calcareous shale on the south bank of Tinaja Creek, in the SW1/4NE1/4 sec. 26, T28N, R23E, Colfax County, (USGS D11597).

The fifth faunal zone, that of *Desmoscaphites bassleri,* which coincides with the zone of *Scaphites leei* II, was found in rocks that crop out along the west bank of the Canadian River in the center of sec. 7, T27N, R23E, Colfax County, (USGS D11388). Gray limestone concretions in platy black shale yielded *D. bassleri* (Fig. 15e). Probable associated fossils include *Inoceramus (Cordiceramus) cordiformis, Inoceramus* aff. *I. (Platyceramus) cycloides, Baculites* sp. (ribbed), and *Haresiceras (Mancosiceras)* sp.

The sixth faunal zone, *Scaphites leei* III Reeside, was recognized in the NE1/4NW1/4NW1/4 sec. 28, T26N, R21E, Colfax County (USGS D11827), along an outlet canal from No. 3 Lake. Fossils were found in brown limestone concretions about 8 in. in diameter, associated with orange-weathering, septarian, limestone concretions as large as 6 ft in diameter. With *Scaphites leei* III were *Inoceramus* sp., *Baculites* sp., and *Glyptoxoceras* sp.

The seventh faunal zone, *Scaphites hippocrepis* I (DeKay), was collected at only one locality from a hard, gray limestone concretion 8 in. in diameter, which yielded one pyritic specimen of *S hippocrepis* I. The locality is along Curtis Creek in the NE1/4SW1/4NW1/4 sec. 6, T27N, R23E, Colfax County. Fossils associated with that zone elsewhere are *Baculites* sp., *Placenticeras* sp., *Didymoceras* sp., and *Inoceramus (Platyceramus) cycloides* Wegner (Fig. 14f). The Roman numeral after *Scaphites hippocrepis* refers to the oldest of three chronologic subspecies (Cobban, 1969).

The eighth and uppermost faunal zone of *Scaphites*

FIGURE 12—Fossils mostly from the Smoky Hill Shale Member of the Niobrara Formation. **a,** *Protexanites shoshonensis* (Meek), hypotype USNM 388279 from the lower part of the sandy unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11377 in NW1/4SW1/4 sec. 36, T24N, R21E, Colfax County, New Mexico. **b,** *Inoceramus (Cremnoceramus) rotundatus* Fiege, hypotype USNM 388280 from the upper part of the shale and limestone unit of the Smoky Hill Shale Member at USGS Mesozoic locality D12525 in SW1/4SE1/4 sec. 26, T21N, R22E, Mora County, New Mexico. **c,** *Inoceramus (Cordiceramus) cordiformis* Sowerby, hypotype USNM 388281 from the upper part of the sandy unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11603 in NE1/4 sec. 29, T27N, R23 E, Colfax County, New Mexico. **d,** *Baculites codyensis* Reeside, hypotype USNM 388282 from a limestone concretion in the lower part of the sandy unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11377 in NW1/4SW1/4 sec. 36, T24N, R21E, Colfax County, New Mexico. **e,** *Baculites yokoyamai* Tokunaga and Shimizu, hypotype USNM 388283 from the upper part of the Fort Hays Limestone Member at USGS Mesozoic locality D12522 in NW1/4SE1/4 sec. 26, T21N, R20E, Colfax County, New Mexico. **f, g,** Views of bottom surfaces of thin beds of siltstone from the lower part of the upper shale unit showing touch marks made by ammonites, probably *Clioscaphites vermiformis* (Meek and Hayden). Figured specimens USNM 388284 and 388285 from USGS Mesozoic locality D12562 on the east face of Urraca Mesa southwest of Cimarron in Colfax County, New Mexico. **h,** *Inoceramus (Endocostea) balticus* &ohm, hypotype USNM 388286 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11425 on the east face of Urraca Mesa southwest of Cimarron in Colfax County, New Mexico. i, Fragment of *Inoceramus (Platyceramus) platinus* Logan encrusted by *Pseudoperna congesta* (Conrad), hypotype USNM 388287 from the lower part of the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11307 in NE1/4SE1/4 sec. 26, T30 N, R25E, Colfax County, New Mexico. All figures are natural size.

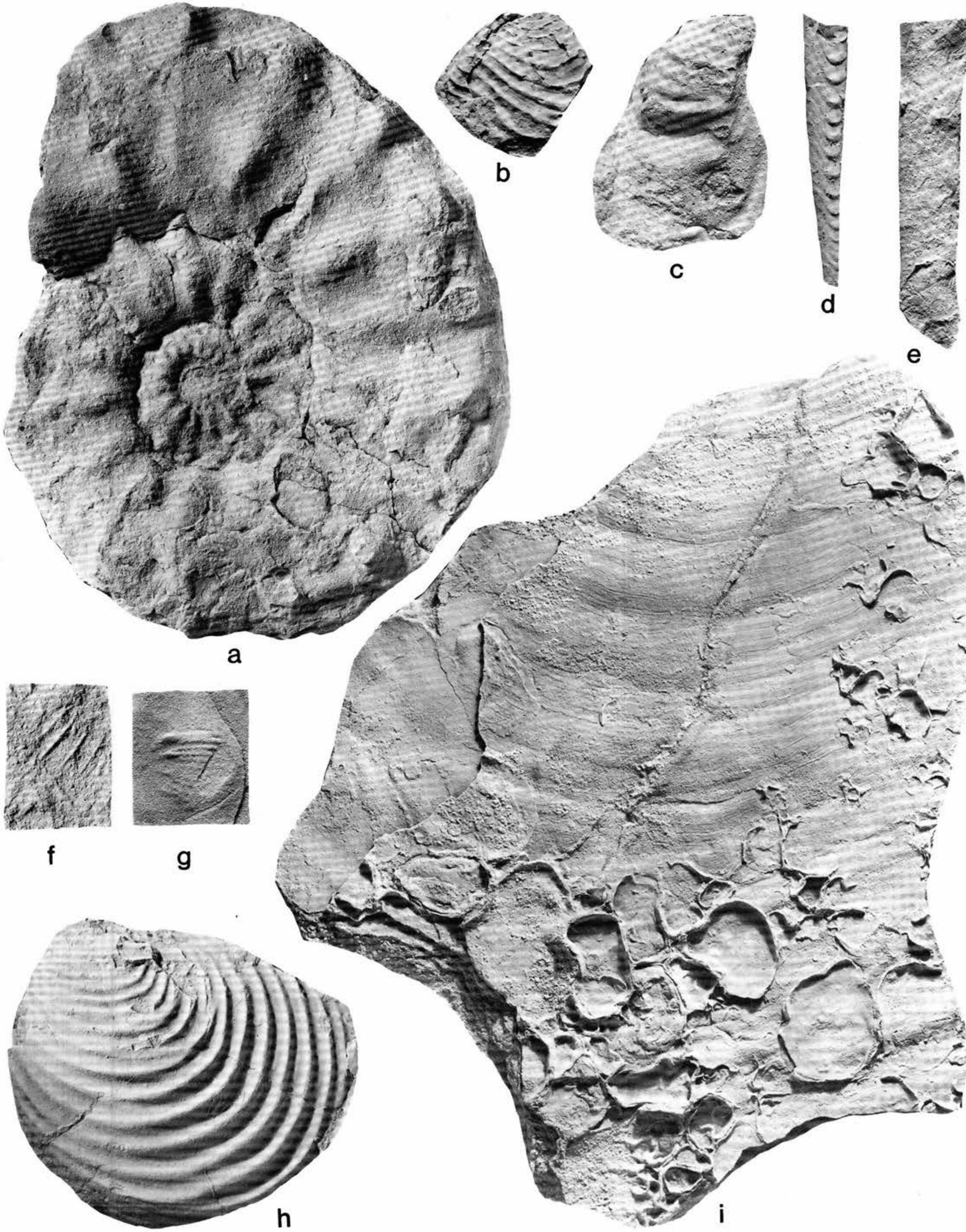
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FIGURE 13—Fossils from the Smoky Hill Shale Member of the Niobrara Formation. **a,** *Inoceramus (Cordiceramus) muelleri* Petrascheck, hypotype USNM 388288 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11422 on the east face of Urraca Mesa southwest of Cimarron in Colfax County, New Mexico. **b, e,** *Protexanites shoshonensis* (Meek), hypotypes USNM 388289 and 388290 from the sandy unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11309 in NE1/4SE1/4 sec. 23, T29N, R25E, Colfax County, New Mexico. **c,** *Phlycticrioceras oregonense* Reeside, hypotype USNM 388291 from the upper part of the lower shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11378 in SW1/4NW1/4 sec. 2, T28N, R26E, Colfax County, New Mexico. **d,** *Inoceramus (Platyceramus) cycloides* Wegner, hypotype USNM 388292 from the same locality as a. f, *Baculites codyensis* Reeside, hypotype USNM 388293 from the lower part of the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11307 in NE1/4SE1/4 sec. 26, T3ON, R25E, Colfax County, New Mexico. All figures are natural size.

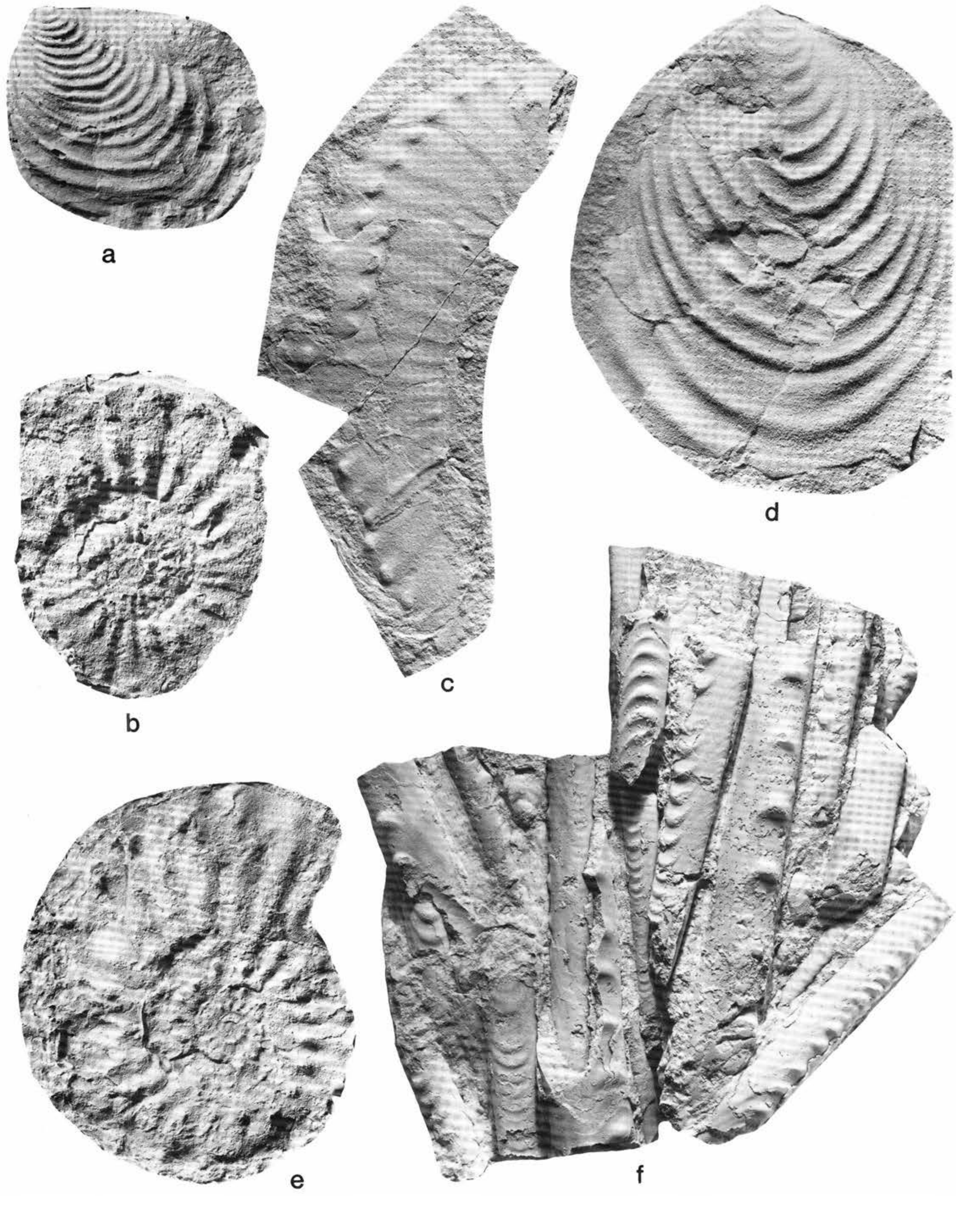
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FIGURE 14—Fossils from the Smoky Hill Shale Member of the Niobrara Formation. **a,** *Glyptoxoceras novimexicanum* (Reeside), hypotype USNM 388294 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11422 on the east face of Urraca Mesa southwest of Cimarron in Colfax County, New Mexico. **b,** *Clioscaphites vermiformis* (Meek and Hayden), hypotype USNM 388295 from the same locality. **c, d,** *Inoceramus (Sphenoceramus) lundbreckensis* McLearn, c, hypotype USNM 388296 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11425 on the east face of Urraca Mesa southwest of Cimarron in Colfax County, New Mexico; d, hypotype USNM 388297 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11824 in NE1/4SW1/4 sec. 7, T25N, R21E, Colfax County, New Mexico. **e, f,** *Inoceramus (Platyceramus) cycloides* Wegner, e, hypotype USNM 388299 from the same locality as c; f, hypotype USNM 388301 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D3646 in SW1/4NW1/4 sec. 6, T27N, R23E, Colfax County, New Mexico. **g,** *Baculites thomi* Reeside, hypotype USNM 388302 from same locality as *c*. **h,** *Inoceramus (Platyceramus)* sp., figured specimen USNM 388300 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11396 in SW1/4NW1/4 sec. 6, T27N, R23E, Colfax County, New Mexico. All figures are natural size.

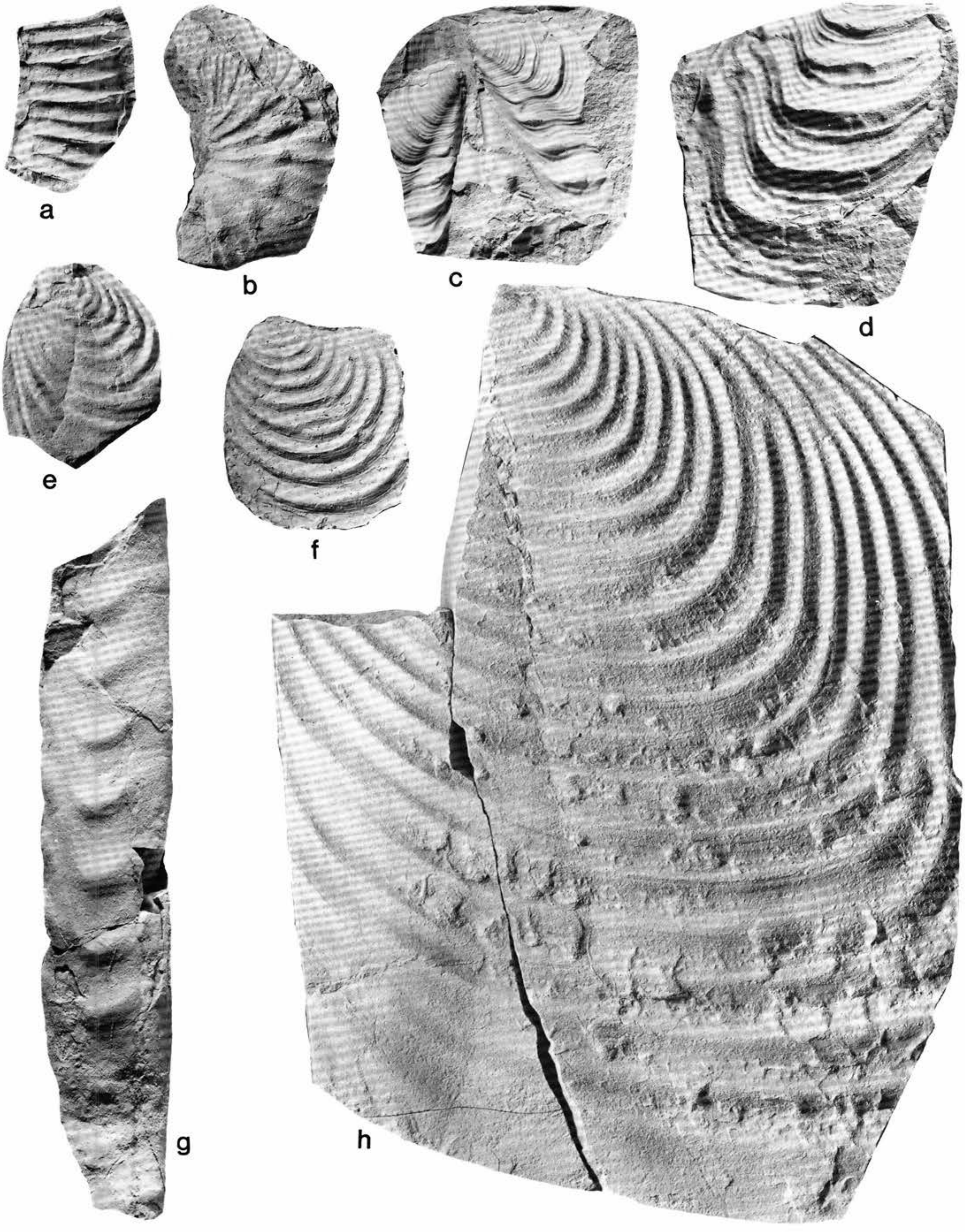
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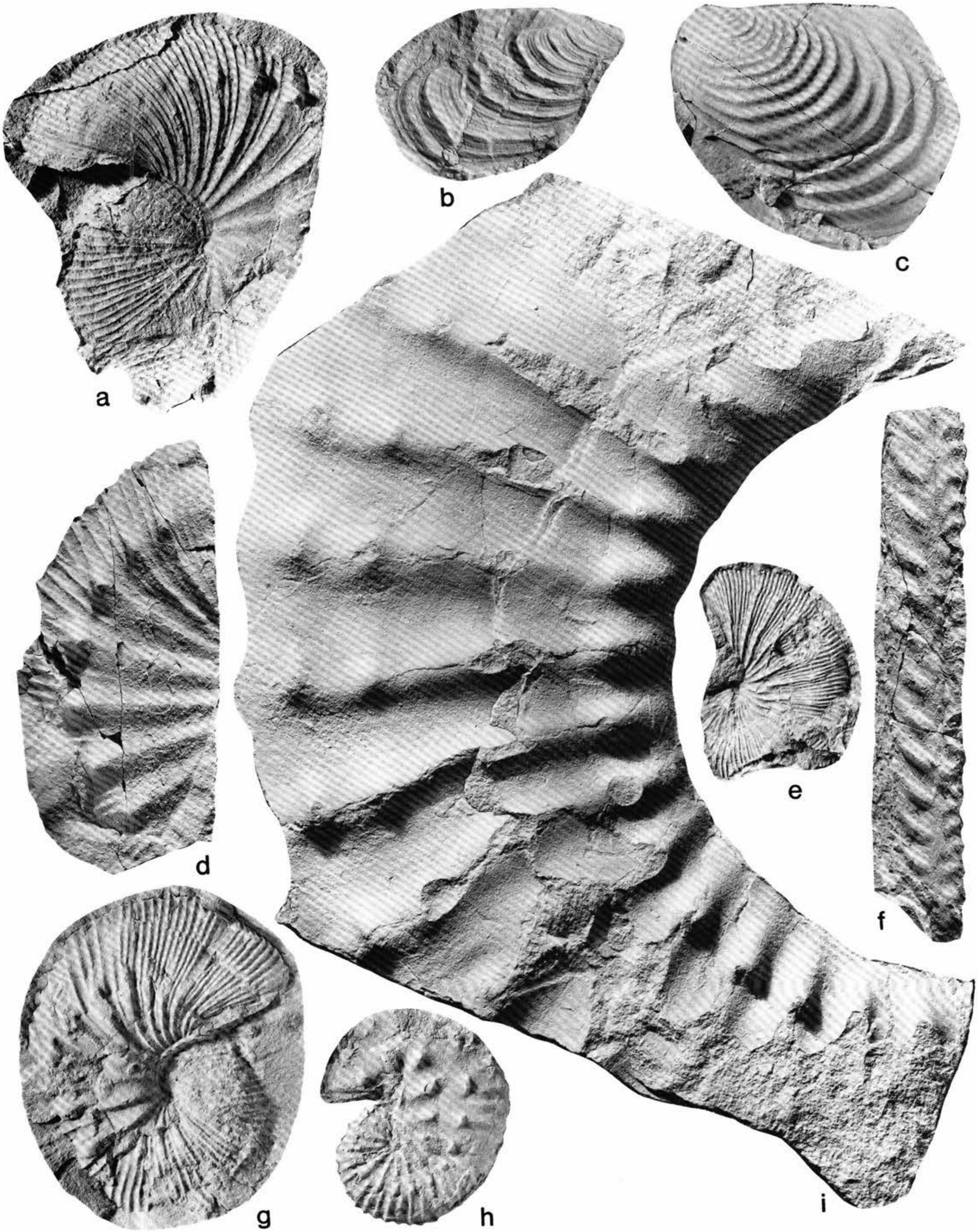
FIGURE 15—Fossils from the Smoky Hill Shale Member of the Niobrara Formation. **a, g,** *Clioscaphites choteauensis* Cobban, a, hypotype USNM 388304 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11386 in sec. 17, T27N, R23E, Colfax County, New Mexico; g, hypotype USNM 388305 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11425 on the east face of Urraca Mesa southwest of Cimarron in Colfax County, New Mexico. b, *Inoceramus (Sphenoceramus) lundbreckensis* McLearn, hypotype USNM 388298 from same locality as g. c, *Inoceramus (Cordiceramus) muelleri* Petrascheck, hypotype USNM 388307 from same locality as g. d, *Desmoscaphites erdmanni* Cobban, hypotype USNM 388306 from same locality as g. **e,** *Desmoscaphites bassleri* Reeside, hypotype USNM 388309 from the upper shale unit of the Smoky Hill Shale Member at USGS Mesozoic locality D11388 in center of sec. 7, T27N, R23E, Colfax County, New Mexico. f, *Baculites thomi* Reeside, hypotype USNM 388303 from same locality as g. h, *Scaphites leei* I Reeside, hypotype USNM 388310 from same locality as g. i, *Texanites omeraensis* (Reeside), hypotype USNM 388308 from same locality as g. All figures are natural size.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hippocrepis II (DeKay), in the upper shale unit, was also found along Curtis Creek in the NW1/4SW1/4NW1/4 sec. 6, T27N, R23E, Colfax County, (USGS D3646). It was in pyritic limestone concretions in black, calcareous shale. Fossils associated with *S. hippocrepis* II are *Baculites haresi* Reeside, *Placenticeras* sp., *Eutrephoceras sp., Inoceramus balticus* Bohm, *I. (Sphenoceramus) lundbreckensis,* and *Nymphalucina* sp.

The age of the lower part of the upper shale unit ranges from early Santonian for *Inoceramus platinus* through late Santonian for *Inoceramus muelleri germanicus* Heinz and *I. bueltenensis* Seitz. The mixed assemblage described earlier seems best assigned to a position high in the upper Santonian beds. *Scaphites hippocrepis* II (DeKay) is early Campanian in age.

Contact with Pierre Shale

The contact of the Smoky Hill Shale Member of the Niobrara Formation with the overlying Pierre Shale is gradational. The upper part of the Smoky Hill Shale Member is chiefly dark-gray to black, platy to fissile, calcareous shale. The lower part of the Pierre Shale is dark-gray to black, noncalcareous, platy to blocky shale. Both contain orange-weathering limestone beds. The top of the calcareous beds seems to range somewhat in stratigraphic position, but apparently lies between the faunal zones of *Scaphites hippocrepis* II and *Scaphites hippocrepis* III.

Correlation with the Niobrara Formation near Pueblo, Colorado

Correlation of the Niobrara in the Raton—Springer area with the formation near Pueblo (Scott and Cob-ban, 1964) shows that the faunal sequences in the two areas differ only slightly; however, the lithology of the Niobrara between the two areas differs significantly (Table 1, Fig. 16).

The faunal zone of *Inoceramus (Cremnoceramus) deformis* Meek, which is in the upper part of the Fort Hays Limestone Member near Pueblo, is in the lower part of the lower shale unit of the Smoky Hill Member in the Raton—Springer area. Fossils near the upper boundary of the Niobrara in the two areas probably are correlative. In the Pueblo area, *Haresiceras placentiforme* Reeside, *Scaphites* cf. *hippocrepis* (DeKay), and *Baculites* cf. *haresi* Reeside were found 78 ft below the top of the Niobrara. In the Raton—Springer area, the uppermost fossil zone contains *Scaphites hippocrepis* II, equivalent to the zone of *Haresiceras placentiforme;* therefore, the top of the Niobrara appears to be of the same age in the two areas.

Lithologic differences in the Fort Hays Limestone of the two areas are slight. The major difference in the Smoky Hill Member is the absence of the sandy unit in the Pueblo area. Outcrops of the Fort Hays near Pueblo contain very little shale, whereas in the Raton—Springer area they contain more shale than limestone. The middle part of the Niobrara in the Raton basin, New Mexico, is largely composed of sandstone (the sandy unit of the Smoky Hill Shale Member) and is more than 10 times as thick as at Pueblo. At Pueblo, beds correlative with the sandy unit of New Mexico are calcareous shale and some platy limestone. The *Clioscaphites vermiformis* zone in the middle shale unit of the Smoky Hill Shale Member near Pueblo apparently is only a few feet thick, whereas in the Raton—Springer area it is more than 175 ft thick.

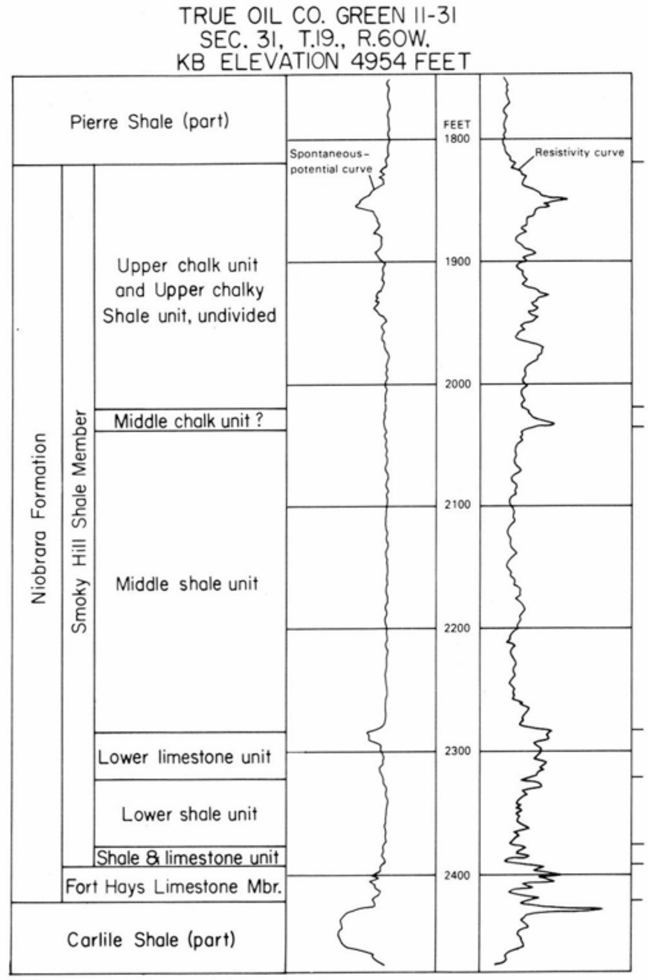

FIGURE 16—Representative electric log of the Niobrara Formation in Pueblo County, Colorado.

The lithology of the upper part of the Niobrara Formation in the two areas also differs markedly. The upper chalky shale unit of the Pueblo area is a calcareous shale, whereas in the Raton—Springer area the equivalent section is shale that contains thin beds of orange-weathering limestone. The thick, oil-producing, upper chalk unit of the Pueblo area is either absent in the Raton—Springer area or is represented by a thin, hard, orange-weathering limestone.

Organic composition

The Niobrara Formation of the Western Interior contains source rocks and reservoir beds, and yields hydrocarbons at fields on the eastern flank of the Denver Basin in Colorado, Nebraska, and Kansas (Pollastro and Scholle, 1984). Samples of shale were collected from outcrops of the Niobrara at eight localities (Table 1) in northeastern New Mexico as part of an evaluation of potential source rocks for oil and gas in the Raton basin. Geochemical data from analyses for organic-carbon content and pyrolytic hydrocarbon yield (Table 2) were supplied by T. A. Daws of the U.S. Geological Survey. Interpretations of these data were reviewed and supplemented by G. E. Claypool of the U.S. Geological Survey.

The amount of organic carbon in a sample (Table 3) is estimated from the sum of the carbon fraction of the total pyrolysis yield plus the carbon yield from combustion of the rock residue (after pyrolysis) at 600°C in open air. Organic-carbon content is the amount of organic matter preserved in the rock after diagenesis and metamorphism.

Hydrocarbons in the samples were estimated from pyrolysis assay, using the Rock—Eval procedure of Espitalie et al. (1977). The results (Table 3) are reported as S_1—free or absorbed hydrocarbons in the rock, S_2—hydrocarbons produced mainly by pyrolysis of solid organic matter, S_3—carbon dioxide produced by pyrolysis of organic matter, and $T(S_2)$—temperature of maximum pyrolytic yield. The genetic potential or total hydrocarbon yield ($S_1 + S_2$) is a semiquantitative determination of the original hydrocarbon-generating capacity of the sampled rock. The hydrogen index (HI), which is the pyrolytic hydrocarbon yield (S2) normalized by the organic-carbon content, is used to determine the type of organic matter in a sample. Similarly, the oxygen index (0I) is the pyrolytic organic-CO_2 yield (S_3) normalized by the organic-carbon content, which also helps to evaluate the type of organic matter. The transformation ratio or production index ($S_1/S_1 + S_2$), as well as the temperature of maximum pyrolytic yield [$T(S_2)$], reflect the thermal maturity of organic matter in the sampled strata.

TABLE 2—Localities and descriptions of outcrop samples of the Niobrara Formation in the Raton basin, New Mexico.

Sample No.	County	Locality (Sec.–T.–R.)	Member	Unit	Lithology
18	Colfax	28–25N–19E	Smoky Hill Shale	lower shale	calcareous shale
19	Colfax	2–24N–19E	Smoky Hill Shale	sandy unit	calcareous silty shale
20	Colfax	33–25N–22E	Fort Hays Limestone		calcareous shale
24	Union	31–31N–28E	Fort Hays Limestone		calcareous shale
31	Colfax	31–27N–23E	Smoky Hill Shale	sandy unit	calcareous shale
32	Colfax	33–25N–22E	Smoky Hill Shale	lower shale	calcareous shale
41	Mora	27–21N–22E	Smoky Hill Shale	lower shale	calcareous shale
44	Colfax	2–28N–26E	Smoky Hill Shale	lower shale	calcareous shale

TABLE 3—Organic composition of sampled rocks.

Sample parameter	Sample number (localities described in Table 2)							
	18	19	20	24	31	32	41	44
Organic carbon (wt %)	1.27	1.22	1.49	1.09	2.35	0.62	3.08	0.84
S_1 (mg/g) – free or absorbed hydrocarbons in the rock	0.04	0.06	0.03	0.01	0.64	0.05	1.37	0.07
S_2 (mg/g) – hydrocarbons produced mainly by pyrolysis of solid organic matter	0.56	0.64	0.56	0.49	3.23	0.21	5.06	0.64
S_3 (mg/g) – carbon dioxide produced by pyrolysis of organic matter	0.54	0.78	0.79	0.67	1.00	0.07	0.35	0.15
T (S_2) (in C°)	443	442	445	434	438	447	442	434
Genetic potential (ppm) – total hydrocarbon yield ($S_1 + S_2$)	600	700	590	500	3870	260	6430	710
HI (mg hydrocarbon/carbon) – hydrogen index, pyrolytic hydrocarbon yield normalized by organic carbon content	44	52	37	44	137	33	164	76
OI (mg carbon dioxide/carbon) – oxygen index, pyrolytic organic carbon-dioxide yield normalized by organic-carbon content	42	63	53	61	45	11	11	17
Transformation ratio ($S_1/S_1 + S_2$)–production index	0.07	0.09	0.05	0.02	0.17	0.19	0.21	0.10

Source rocks for oil and gas contain at least 0.5% organic carbon (Dickey and Hunt, 1972); consequently, all of the sampled beds in the Niobrara (Table 3) could be potential source rocks. However, the generating capacity or genetic potential of source rocks for oil and possibly gas should be at least 2,000 ppm, according to Tissot and Welte (1978); this indicates that only samples 31 and 41 represent moderate to good source beds for hydrocarbons. The hydrogen and oxygen indexes, generally used to determine the type of organic matter, apparently reflect mixed humic and sapropelic matter in these sampled beds of open marine origin. The thermal maturity required for the generation of oil is reflected by a transformation ratio of at least 0.1 and a temperature of maximum pyrolytic yield of at least 435°C. The evidence of thermal maturity is conflicting, but apparently samples 18, 20, and 24 are thermally immature and samples 31, 32, and 41 are mature. Samples 19 and 44 might be mature. These interpretations have not considered the possibly significant effects of surface weathering. Equivalent unweathered samples would probably indicate more promising source rocks for oil and gas.

Measured sections

Scott measured nine stratigraphic sections that include all or part of the Fort Hays Limestone Member of the Niobrara Formation. The number and thickness of beds in the member vary slightly between sections, even where the sections are near each other. For this reason, we were generally unable to correlate specific beds over long distances.

Section 1

SW¼ sec. 33, T25N, R22E, Colfax County, Springer 7½′ quadrangle (Fig. 1).

Smoky Hill Shale Member (part), shale and limestone unit (measured west of I-25 along Salado Creek):

		Thickness ft	in.
46.	Covered		
45.	Shale, gray, hard, platy	2	
44.	Bentonite, yellowish brown		¼
43.	Limestone, gray; weathers shaly		3
42.	Shale, gray	8	
41.	Limestone, gray		4
40.	Shale, gray		10
39.	Limestone, gray		11
38.	Bentonite, orange		¼
37.	Limestone, gray; weathers shaly		9
36.	Shale, gray	3	4
35.	Limestone, gray, shaly		8
34.	Limestone, gray, moderately hard		5
33.	Shale, gray	3	7
32.	Limestone, gray	?	
31.	Covered		
30.	Limestone, gray		4+
29.	Shale, gray	2	3
28.	Limestone, gray		2
27.	Shale, gray; faulted?		6
26.	Limestone, gray, platy		8
25.	Shale, gray		3
24.	Limestone, gray		9
23.	Shale, light gray		2½
22.	Limestone, gray		2½
21.	Shale, gray; ⅛ in. thick bentonite 3 in. below top	2	4
20.	Limestone, gray, hard; weathers shaly in upper part	2	2

		Thickness ft	in.
	(Beds below measured east of I-25)		
19.	Shale, gray	1	3
18.	Limestone, gray, shaly	1	6
17.	Shale, gray		7
16.	Limestone, gray, shaly		8
15.	Shale, yellowish gray	1	
	Exposed thickness of shale and limestone unit	35	11½
	Fort Hays Limestone Member:		
14.	Limestone, gray, massive; weathers to irregular pieces; hard, dense	1	7
	USGS D11969, NE¼NW¼ sec. 4, T24N, R22E, Colfax Country: *Inoceramus parvus* Tröger; *I. incertus* Jimbo?; *Margostrea?* sp.; *Ostrea* sp.; *Baculites* sp.; *Eutrephoceras* sp.		
13.	Shale, gray	1	7
12.	Limestone, gray, hard; contains *Inoceramus*	1	
11.	Shale, gray, calcareous		11
10.	Limestone, gray, hard	1	5
	USGS D11970: *Inoceramus incertus mytiloidiformis* Tröger; *I.* aff. *labiatoidiformis* Tröger (of Keller)		
9.	Shale, gray, calcareous	1	7
8.	Limestone, gray, hard	1	5
	USGS D12443: *Inoceramus* aff. *labiatoidiformis* Tröger (of Keller)		
7.	Shale, gray, calcareous	1	1
6.	Limestone, gray, hard		7
5.	Shale, gray, calcareous		8
4.	Limestone, gray, hard. Marker bed	2	
	USGS D12442: *Inoceramus* cf. *longealatus* Tröger		
3.	Shale, gray, calcareous		8
2.	Limestone, gray; weathers yellowish gray	2	6
	Total thickness of the Fort Hays Limestone Member	17	1
	Carlile Shale (part), unnamed shale member (part):		
1.	Shale, gray, calcareous		3

Section 2

Moras Creek area in the NW¼NE¼ sec. 5, T24N, R19E, Colfax County, Miami quadrangle (Fig. 1).

Fort Hays Limestone Member (part):

	Thickness ft	in.
9. Limestone		8
8. Shale	1	6
7. Limestone, gray		8
6. Shale, gray	2	
5. Limestone, gray		5½
4. Shale, gray; becomes part of units 3 and 5 where unweathered		3
3. Limestone, gray		7
USGS D11829:		
Inoceramus incertus Jimbo		
2. Shale, gray	2	6
1. Limestone, gray	1	2½
USGS D11828:		
Inoceramus aff. *labiatoidiformis* Tröger (of Keller)		
Exposed thickness of Fort Hays Limestone Member	9	10

Section 3

Faulted area in the NE¼NW¼ sec. 5, T24N, R19E, Colfax County, Miami quadrangle (Fig. 1). (Alternative, and probably correct, version of section 2.)

Fort Hays Limestone Member (part):

	Thickness ft	in.
7. Limestone	1	3
6. Shale	1	8
5. Limestone		10
4. Shale	2	
3. Limestone, has parting a little above middle	1	2
USGS D11832:		
Inoceramus parvus Tröger		
2. Shale	2	6
1. Limestone	1	
Exposed thickness of Fort Hays Limestone Member	10	5

Section 4

SE¼NE¼ sec. 17, T24N, R22E, Colfax County, Springer quadrangle (Fig. 1).

Fort Hays Limestone Member (part):

	Thickness ft	in.
15. Limestone	1	4+
14. Shale, olive ray	1	9
13. Limestone	1	2
12. Shale		7
11. Limestone, gray; contains *Inoceramus*	1	3
10. Shale, dark gray	1	5
9. Limestone, gray	1	6
8. Shale, dark gray	1	2
7. Limestone, gray		7
6. Limestone, gray, shaly		3
5. Shale, olive gray		5
4. Limestone, gray. Marker bed	2	2
3. Shale, dark gray		8½
2. Limestone, gray	1	3
Exposed thickness of Fort Hays Limestone Member	15	6½
Carlile Shale, unnamed shale member (part):		
1. Shale, gray		10

Section 5

Floor of Arroyo Piedra Lumbre in the NE¼NW¼ sec. 7, T21N, R23E, Mora County, Alto de Hormiga quadrangle (Fig. 1).

Fort Hays Limestone Member (part):

	Thickness ft	in.
19. Limestone, gray, hard	?	
18. Shale, gray	?	
17. Limestone, gray, hard	?	
16. Shale, gray	1?	
15. Limestone, gray, hard	1	
USGS D12524:		
Inoceramus cf. *longealatus* Tröger		
14. Shale, gray		7
13. Limestone, gray	1	7
USGS D12523:		
Inoceramus incertus Jimbo		
Inoceramus incertus labiatoidiformis (Tröger)		
Prionocyclus sp.		
12. Shale, gray	2	
11. Limestone, gray	1	2
10. Shale, gray		11
9. Limestone, gray	1	3
8. Shale, gray	2	
7. Limestone, gray	1	9
6. Shale, gray	1	7
5. Limestone, gray	1	
4. Shale, gray		11
3. Limestone, gray	2	7
2. Shale, gray		11
1. Limestone, gray	1	8
USGS D11836:		
Inoceramus aff. *labiatoidiformis* Tröger (of Keller)		
Prionocyclus sp. (probably *P. quadratus*)		
Exposed thickness of Fort Hays Limestone Member	21	11

Section 6

Arroyo Piedra Lumbre in the SE¼NW¼ sec. 7, T21N, R23E, Mora County, Alto de Hormiga quadrangle (Fig. 1).

Fort Hays Limestone Member (part):

	Thickness ft	in.
20. Shale, gray		
19. Limestone, gray		2
18. Shale, gray	2	6±
17. Limestone, gray	1	2

	Thickness ft	in.
16. Shale, gray, hard	2	1
15. Limestone, shaly in uppermost 5 in.	2	1
14. Shale, gray		2
13. Limestone, gray		2
12. Shale, dark gray, hard	2	
11. Limestone, gray	1	1
10. Shale, gray		6
9. Limestone, shaly		3
8. Shale, gray		3
7. Limestone, shaly	1	4
6. Shale, gray		7
5. Limestone, gray, shaly	1	5
4. Shale, gray		5
3. Limestone, gray	1	8
2. Shale, gray	1	6
1. Limestone, gray	1	
Exposed thickness of Fort Hays Limestone Member	20	4

Section 7

Measured by G. R. Scott and R. A. Wobus at the SE corner of sec. 36, T31N, R27E, Colfax County, Robinson Peak quadrangle (Fig. 1).

Fort Hays Limestone Member:

	Thickness ft	in.
17. Limestone	1	2+
16. Shale		7
15. Limestone		10
14. Shale		4
13. Limestone		8
12. Shale		6
11. Limestone	1	7
10. Shale		10
9. Limestone	1	1
8. Shale		6
7. Limestone	1	3
USGS D11971: *Inoceramus* aff. *labiatoidiformis* Tröger (of Keller, 1982) *Pycnodonte* sp.		
6. Shale	1	4
5. Limestone	1	1
4. Shale	1	
3. Limestone		6
2. Shale		4
1. Limestone	3	10+
Exposed thickness of Fort Hays Limestone Member	17	5

Section 8

Road bed in the NE¼SE¼NE¼ sec. 5, T26N, R25 E, Colfax County, Tres Hermanos Peak quadrangle (Fig. 1). Thicknesses were measured in a shallow trench; therefore, most limestone beds probably are thinner than normal.

Fort Hays Limestone Member:

	Thickness ft	in.
10. Limestone, gray, hard		4
USGS D11967: *Inoceramus incertus* Jimbo *I. incertus mytiloidiformis* Tröger *I.* aff. *labiatoidiformis* Tröger (of Keller) *Prionocyclus* sp.		
9. Shale		8
8. Limestone		6
7. Shale		8
6. Limestone		4
5. Shale		7
4. Limestone, gray, massive; weathers to irregular blocks. Marker bed	1	9
3. Shale, gray, calcareous		9
2. Limestone, gray, massive; weathers to irregular blocks	1	4
Exposed thickness of Fort Hays Limestone Member	6	11
Carlile Shale (part), unnamed shale member (part):		
1. Shale, gray, calcareous. Contains *Inoceramus*	12	

Section 9

SW¼NW¼ sec. 5, T24N, R23E, Colfax County, Springer quadrangle (Fig. 1).

Fort Hays Limestone Member:

	Thickness ft	in.
10. Limestone	1	2
9. Shale, yellowish brown	1	
8. Limestone	1	4
7. Shale, gray	1	
6. Limestone		7
5. Shale		8
4. Limestone. Marker bed for correlation	1	10
3. Shale, gray		7
2. Limestone	1	4
Exposed thickness of Fort Hays Limestone Member	9	6
Carlile Shale, unnamed shale member:		
1. Shale, gray, calcareous		11

Section 10

SW¼SE¼ sec. 26, T21N, R22E, Mora County, Alto de Hormiga quadrangle (Fig. 1).

Smoky Hill Shale Member (part), lower shale unit (part):

	Thickness ft	in.
7. Shale, olive gray	15	
USGS D12526: *Inoceramus (Volviceramus) grandis* (Conrad)		
6. Limestone, shaly		4
5. Shale, olive gray, platy, calcareous	8	
4. Limestone, olive gray, shaly. Contains baculites and oysters		5
3. Shale, olive gray, platy	1	3
Exposed thickness of lower shale unit	10	

	Thickness ft	in.
Shale and limestone unit (part):		
2. Limestone, gray; weathers to 3 or 4 ledges	2	4
USGS D12525: *Inoceramus (Cremnoceramus) rotundatus* Fiege		
1. Shale, dark gray, platy	5	
Exposed thickness of shale and limestone unit	7	4

Section 11

NW¼SW¼ sec. 16, T28N, R26E, Colfax County, Mesa Larga quadrangle (Fig. 1).

Smoky Hill Shale Member (part), shale and limestone unit (part):

	Thickness ft	in.
12. Limestone, gray, irregular bedding. Contains *Inoceramus*		6
11. Shale, yellowish gray		6
10. Limestone, gray, irregularly platy		2
9. Shale, yellowish gray	12	
8. Limestone, gray, platy weathering		8
7. Shale, yellowish gray, flaky weathering	5	
6. Limestone, gray, platy		4
5. Shale, yellowish gray, flaky weathering	3	11
4. Limestone, gray, platy		4
3. Shale, yellowish gray, flaky weathering. Includes a weathered limestone bed at 12 in. above the base	4	2
2. Limestone, gray, platy		4
1. Shale, yellowish gray, calcareous; resembles a shaly limestone	3	9
Exposed thickness of shale and limestone unit	31	8
Fort Hays(?) Limestone Member		

Section 12

SE¼SW¼ sec. 34, T27N, R24E, Colfax County, Loco Arroyo quadrangle (Fig. 1).

Smoky Hill Shale Member (part), shale and limestone unit (part):

	Thickness ft	in.
21. Limestone, gray		5
20. Shale, gray	2	6
19. Shale, gray, platy		9
18. Shale, gray	1	3
17. Limestone, gray; weathers shaly		5
16. Shale, gray		7
15. Limestone, gray. Contains *Inoceramus*		5
14. Shale, gray	1	2
13. Limestone, gray; uppermost 7 in. weathers platy	1	2
12. Shale, gray		8
11. Limestone, gray, platy	1	
10. Shale	1	3
9. Limestone, gray, shaly		3
8. Shale, gray		7

	Thickness ft	in.
7. Limestone, gray, hard, shaly		11
6. Shale, gray	4	
Section faulted; unknown amount of stratigraphic throw.		
5. Shale, gray	6	6
4. Limestone, gray. Contains *Inoceramus*		8
3. Shale, gray		10
2. Limestone, gray; weathers shaly to irregular plates		4
1. Shale, gray, calcareous, well laminated	6	
Exposed thickness of shale and limestone unit	31	8

Section 13

SE¼ sec. 26, T24N, R21E, Colfax County, Piñon Hills quadrangle (Fig.1).

Smoky Hill Shale Member (part), sandy unit (part):

	Thickness ft	in.
25. Sandstone, yellowish brown, fine grained, shaly, in thin lenses rarely more than one inch thick	192+	
USGS D11434, from 120 ft above base: *Neocrioceras?* sp.		
USGS D11435, from 96 ft above base: *Inoceramus (Magadiceramus) subquadratus* Schlüter; *Protexanites shoshonensis* (Meek)		
A calcarenite bed in about this position contains fish teeth.		
USGS D11377 in the NW¼ SW¼ sec. 36, T24N, R21E, Colfax County, from 65 ft above base: *Inoceramus (Magadiceramus) subquadratus subquadratus* Schlüter (Fig. 9a, b); *I. (M.) subquadratus crenelatus* Seitz (Fig. 9c-f); *I. (M.)* aff. *soukupi* Macak (Fig. 9j); *Protexanites shoshonensis* (Meek) (Fig. 12a); *Baculites asper* Morton; *B. codyensis* Reeside (Fig. 12d)		
USGS D11433, from 10 ft above base: *Inoceramus (Volviceramus) grandis* (Conrad)		
Lower shale unit:		
24. Shale, black, fissile; contains *Inoceramus (Volviceramus) grandis* (Conrad) throughout	95±	
USGS D11432: Rudist [aff. *Durania austinensis* (Roemer); ident. by N. F. Sohl]		
23. Bentonite, orange		9
22. Shale and platy limestone, in repetitions of underlying beds	16	
21. Limestone, platy		5
20. Shale, black, fissile		4
19. Limestone, platy		4
18. Shale, black, fissile		4
17. Limestone, platy		5
Total thickness of lower shale unit	113	7

	Thickness ft	in.
Shale and limestone unit (part):		
16. Shale, contains thick fragments of *Inoceramus* shells	3	4
15. Limestone		6
14. Shale	1	8
13. Limestone, gray, platy, shaly		3
12. Shale, gray	5	
11. Limestone, gray; weathers light gray, shaly		4
10. Shale, gray	1	6
9. Limestone, gray; weathers light gray, shaly		7
8. Shale, gray	1	4
7. Limestone, gray, platy		6
6. Shale, yellowish gray	3	
5. Limestone, gray, shaly; contains concretionary mass 2 ft in diameter; upper and lower parts highly bioturbated	2	9
4. Shale, yellowish gray	3	4
3. Limestone, gray, shaly	1	
2. Shale, yellowish gray		6
1. Limestone, gray, shaly		8+
Exposed thickness of shale and limestone unit	26	3

Section 14

East side of round knob in the SW¼NW¼ sec. 2, T28N, R26E, Colfax County, Mesa Larga quadrangle (Fig. 1).

Smoky Hill Shale Member (part), sandy unit (part):

	Thickness ft	in.
8. Shale, yellowish gray, calcareous, platy; weathers grayish orange; contains thin lenses of moderately yellowish-brown sandstone; sparsely fossiliferous. Forms ridges.		
Exposed thickness of sandy unit	20	
Lower shale unit (part):		
7. Shale; weathers yellowish gray; platy, calcareous, non-sandy	6	
6. Calcarenite; weathers reddish brown.		1
USGS D11407:		
Pseudoperna congesta (Conrad)		
Shark teeth and fish bones		
5. Limestone, gray; weathers yellowish gray; beds about 4–12 in. thick, separated by shaly limestone beds. Bentonite bed about 3 in. thick is 10 in. above base. Contains abundant fragments of *Inoceramus* above middle	13	
USGS D11378 (Faunal zone of *Scaphites depressus):*		
Inoceramus (Platyceramus) platinus Logan		
I. (Magadiceramus) subquadratus Schlüter		
I. (Volviceramus) sp.		
Pseudoperna congesta (Conrad)		
Baculites sp.		
Phlycticrioceras oregonense Reeside (Fig. 13c)		
4. Shale, dark gray, calcareous, platy; contains about five dark gray, platy, limestone layers as much as 12 in. thick	9	6
3. Shale, dark gray, moderately hard, platy, calcareous	11	
Exposed thickness of lower shale unit	39	7
Faults of unknown throw		
Shale and limestone unit (part):		
2. Shale, dark gray, irregularly bedded, calcareous. Contains shaly limestone layers 6–8 in. thick	14	
1. Limestone, gray	3+	
Exposed thickness of shale and limestone unit	17	

Section 15

SE¼SW¼ sec. 7, T25N, R19E, Colfax County, Miami quadrangle (Fig. 1).

Smoky Hill Shale Member (part), upper shale unit (part):

	Thickness ft	in.
17. Shale, gray, flaky, sandy to silty, calcareous. Contains no limestone beds or concretions	110+	
16. Limestone, gray; weathers orange; dense, hard, conchoidal fracture	10	
USGS D11425:		
Inoceramus (Cordiceramus) muelleri Petrascheck (Fig. 15c)		
I. (Endocostea) balticus Böhm		
I. (Sphenoceramus) lundbreckensis (McLearn) (Figs. 14c, 15b)		
Baculites thomi Reeside (Figs. 14g, 15f)		
Scaphites leei I Reeside (Fig. 15h)		
Clioscaphites choteauensis Cobban (Fig. 15g)		
Desmoscaphites erdmanni Cobban (Fig. 15d)		
Texanites omeraensis (Reeside) (Fig. 15i)		
Reginaites leei (Reeside)		
15. Shale, gray, slightly sandy, flaky	29	6
14. Limestone gray; weathers orange; platy, dense	1	2
USGS D11423:		
Clioscaphites vermiformis (Meek and Hayden)		
Baculites codyensis Reeside		
Pseudoperna congesta (Conrad)		
Inoceramus aff. *platinus* Logan		
13. Shale, olive gray, sandy, platy	12	6
12. Limestone, gray; weathers orange; sandy, platy. Contains *Inoceramus (Cladoceramus) undulatoplicatus, Pseudoperna congesta, Pteria* sp., and *Baculites codyensis*?	1	
11. Shale, olive gray, sandy, platy	9	
10. Sandstone, gray; weathers orange; platy		6

	Thickness ft	in.
9. Shale, olive gray, platy, sandy. Contains many fragments of *Inoceramus platinus* covered by *Pseudoperna congesta*	18	
8. Limestone, gray; weathers orange; platy, dense. Contains very large *Inoceramus platinus, Pseudoperna congesta,* and *Baculites codyensis*		9
7. Shale, olive gray, sandy, platy	27	
6. Limestone, gray; weathers orange; platy. Contains *Inoceramus platinus, Pseudoperna congesta, Baculites codyensis,* and *Clioscaphites* sp.	1	1
Exposed thickness of upper shale unit	211	4
Sandy unit (part):		
5. Shale, olive gray, sandy, platy; contains three thin beds of orange-weathering limestone	104	
4. Limestone, gray, sandy, platy		10
USGS D11424:		
Inoceramus sp.		
Pseudoperna congesta (Conrad)		
Phelopteria sp.		
Clioscaphites vermiformis (Meek and Hayden)		
Baculites codyensis Reeside		
3. Shale, olive gray, platy, mostly sandy	28	
2. Limestone, gray; weathers orange; platy, dense; breaks with conchoidal fracture where unweathered	1	3
USGS D11422:		
Inoceramus (Platyceramus) platinus Logan		
I. (Cordiceramus) muelleri Petrascheck		
Pseudoperna congesta (Conrad)		
Baculites codyensis Reeside		
Glyptoxoceras sp.		
Clioscaphites vermiformis (Meek and Hayden)		
fish scales		
1. Shale, olive gray, platy to flaky; contains some sandy lenses and plates in upper part. Sandy beds stand out in relief	(not measured)	
Exposed thickness of measured sandy unit	134	1

Section 16

South flank of Eagle Tail Mountain in the SW¼NE¼ sec. 24, T28N, R23E, Colfax County, Eagle Tail Mountain quadrangle (Fig. 1).

Smoky Hill Shale Member (part), upper shale unit (part):

	Thickness ft	in.
7. Shale, gray, calcareous, fissile; contains in upper part thick pieces of *Inoceramus* shell coated with *Pseudoperna congesta*	+78	
6. Limestone, gray; weathers orange; earthy; contains fish scales		9
5. Shale, gray	6	
4. Limestone, gray; weathers orange	1	
USGS D11598:		
Inoceramus sp. (some larger than 22 in. in diameter)		
Baculites sp. (smooth)		
Haresiceras (Mancosiceras) sp.		
fish scales and petrified wood		
3. Shale, gray; contains a limestone concretion about 8 in. thick 1 ft below top	15	
2. Limestone, gray; weathers orange. Contains *Pseudoperna congesta,* smooth baculites, fish scales, and bones	1	6
1. Shale, gray	20	
Exposed thickness of upper shale unit	122	3

Section 17

Above top of sandy beds in south bank of Kappis Arroyo in the NE¼NE¼ sec. 22, T27N, R23E, Colfax County, Loco Arroyo quadrangle (Fig. 1).

Smoky Hill Shale Member (part), upper shale unit (part):

	Thickness ft	in.
4. Shale, gray. Contains *Inoceramus (Platyceramus) platinus* and *Pseudoperna congesta*		
3. Limestone, gray; weathers yellowish orange; chalky, earthy. Contains *Inoceramus* more than 22 in. in diameter and many pelagic foraminifera	2	6
2. Shale, gray, fissile, silty, micaceous, calcareous	6	
Exposed thickness of upper shale unit	8	6
Sandy unit (part):		
1. Interlayered shale, yellowish gray, sandy, and fine-grained sandstone, platy; contains *Baculites codyensis;* also contains oval gray limestone concretions 20 in. in diameter by 9 in. thick that contain brown calcite and white barite, but no fossils	10	
Exposed thickness of sandy unit	10	

Section 18

Measured along Curtis Creek in the NW¼SW¼NW¼ sec. 6, T27N, R23E, Colfax County, Maxwell quadrangle (Fig. 1).

Smoky Hill Shale Member (part), upper shale unit (part):

	Thickness (approx.) ft	in.
8. Limestone concretions, gray, dense, hard; many contain cores of granular calcite		6±

	Thickness ft	in.
USGS D3646:		
Inoceramus (Platyceramus) cycloides Wegner (Fig. 13d)		
Scaphites hippocrepis I (DeKay)		
Baculites sp.		
7. Shale, calcareous....................	10±	
6. Limestone concretion, gray, dense, 3 ft long; contains abundant *Inoceramus* cf. *simpsoni*, *Scaphites* sp., and *Baculites* sp.	1	8
5. Shale, calcareous....................	5±	
4. Limestone concretions, gray; weather orange; hard, dense, jointed vertically, split poorly along bedding		10
USGS D11396:		
Inoceramus (Platyceramus) sp. (Fig. 14h)		
3. Shale, calcareous....................	5±	
2. Limestone concretions, gray; overlain by 2 in. thick layer of gray, silty, hard, platy shale. Concretions contain sparse *Inoceramus* cf. *platinus*		3
1. Shale, calcareous; 2 ft below the top is a 10 in. thick bed of more resistant shale. Four inches below top of resistant shale are gray limestone concretions, similar to those of bed 8, that contain *Inoceramus* cf. *platinus*...............	30±	
Approximate exposed thickness of upper shale unit.............................	53	3±

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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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Type *face:* Palatino

Presswork: Miehle Single Color Offset
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