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MID-CRETACEOUS MOLLUSCAN RECORD FROM WEST-CENTRAL NEW MEXICO

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Abstract—Molluscan fossils are fairly abundant in most of the mid-Cretaceous rocks of west-central New Mexico. The important guide fossils are reviewed and illustrated. The fossils are from the following rocks, from oldest to youngest: middle Cenomanian into lower part of upper Cenomanian, intertongued Dakota Sandstone and Mancos Shale; upper Cenomanian into lower or middle Turonian, Rio Salado Tongue of Mancos Shale; upper Cenomanian into upper Turonian or lower Coniacian, main body of Mancos Shale; upper part of lower Turonian into lower part of middle Turonian, Atarque Sandstone; middle Turonian, Semilla Sandstone Member of Mancos Shale; middle Turonian into lower part of upper Turonian, Tres Hermanos Formation; upper Turonian, Juana Lopez Member of Mancos Shale, Pescado Tongue of Mancos Shale, D-Cross Tongue of Mancos Shale, upper part of Tres Hermanos Formation and locally part or all of Gallup Sandstone; lower Coniacian, upper part or locally all of Gallup Sandstone. Younger rocks of later Coniacian age, such as the Mulatto Tongue of the Mancos Shale, are not treated.

INTRODUCTION

The area of this report extends from Albuquerque west to the Arizona state line and from Quemado northward to a little beyond Gallup (Fig. 1), which is essentially the area of the present field conference. Only marine rocks and molluscan fossils of middle Cenomanian through early Coniacian age are discussed in this report (Dakota Sandstone through Gallup Sandstone).

Mid-Cretaceous rocks and fossils of west-central New Mexico have received much attention from as far back as 1858, when Marcou published his report on the geology of North America and described *Ammonites novi-mexicani* from the Rio Puerco valley west of Albuquerque. That ammonite is now classified as *Prionocyclus novimexicanus* (Marcou) (Hook and Cobban, 1979). For excellent summaries of the earlier geological explorations of west-central New Mexico, the reader is referred to Lee (1912, 1917), and for later surveys, Dane (1959), Hook et al. (1983) and Hook (1984). For details of lithology and thickness of mid-Cretaceous rocks described during the last few decades, the reader is referred to Dane and Bachman (1957), Dane et al. (1957, 1968), Landis et al. (1973a, b), Molenaar (1973, 1974, 1983), La Fon (1981), Hook (1983, 1984), Hook et al. (1980, 1983), Maxwell (1982), McLellan et al. (1983a, b) and Anderson (1987). The upper Turonian to lower Coniacian Gallup Sandstone has been extensively treated and mapped by numerous authors (see Kirk et al., 1978, for excellent summary up to 1978).

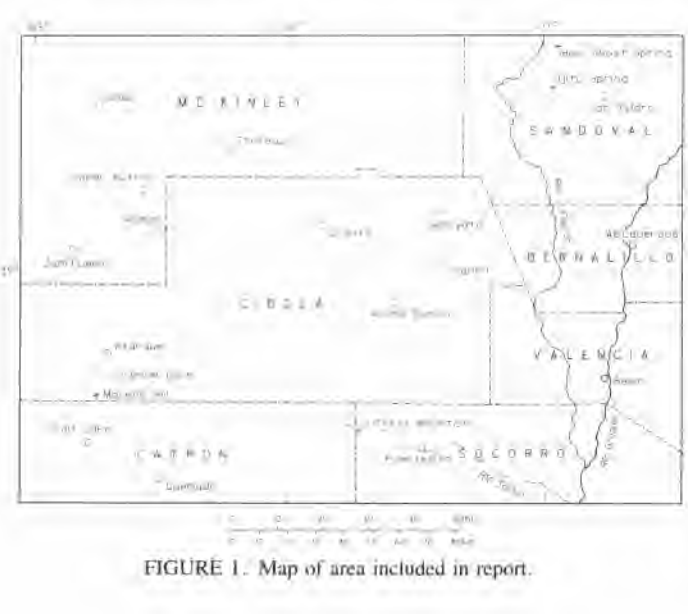

FIGURE 1. Map of area included in report.

STRATIGRAPHY

Rocks of middle Cenomanian through early Coniacian age that contain marine molluscan fossils in west-central New Mexico are the Dakota Sandstone, Mancos Shale, Atarque Sandstone, Tres Hermanos Formation and Gallup Sandstone (Fig. 2). The Dakota Sandstone, of middle and late Cenomanian age, is intertongued with the Mancos Shale, and several members have been proposed (Owen, 1966; Landis et al., 1973a, b). Where best developed in the east-central part of the field conference area (Fig. 2, Acoma Pueblo-Seboyeta area), the intertongued sequence is as follows, from oldest to youngest: Oak Canyon Member of Dakota Sandstone, Cubero Tongue of Dakota Sandstone, Clay Mesa Tongue of Mancos Shale, Paguate Tongue of Dakota Sandstone, Whitewater Arroyo Tongue of Mancos Shale and Twowells Tongue of Dakota Sandstone. The relationships of these members across the southern part of the field conference area have been shown by Hook et al. (1980). The Twowells Tongue is overlain either by the upper Cenomanian to middle Turonian Rio Salado Tongue of the Mancos Shale (Hook et al., 1983) or by an equivalent unnamed shale member of the Mancos Shale (Fig. 2). Over much of the southwestern half of the area, the Rio Salado Tongue is overlain by the Tres Hermanos Formation of middle and early–late Turonian age (Hook et al., 1983). Three members make up the Tres Hermanos; in ascending order they are the Atarque Sandstone Member, Carthage Member and Fite Ranch Sandstone Member. The Carthage Member is nonmarine, whereas the other two members are nearshore marine deposits. Pike (1947) gave the name Atarque as a basal member of the Mesaverde Formation, but Atarque is now applied to a sandstone deposited during shoreline regression following the Rio Salado transgression. In much of the field conference area, the Atarque is a sandstone member at the base of the Tres Hermanos Formation, but in the southwestern part (Moreno Hill-Atarque area), the Atarque Sandstone is treated as a formation that separates the marine Rio Salado Tongue from the nonmarine Moreno Hill Formation (Hook et al., 1983; McLellan et al., 1983a, b; Anderson, 1987). In the south-central part of the area (Acoma Pueblo-D Cross Mountain) and southeastward beyond the Rio Grande, the Tres Hermanos Formation is overlain by the upper Turonian D-Cross Tongue of the Mancos Shale (Dane and Bachman, 1957). The lower part of the D-Cross Tongue extends westward almost to Atarque, where it is known as the Pescado Tongue of the Mancos Shale (Pike, 1947). For relationships of the D-Cross and Pescado tongues, the reader is referred to papers by Molenaar (1973, 1974, 1983), Hook et al. (1983) and Anderson (1987). In the northeastern half of the area, the Tres Hermanos Formation passes into marine Mancos Shale. Seaward of the Tres Hermanos Formation, discontinuous lenses of marine silty to sandy beds have been named the Semilla Sandstone Member of the Mancos Shale (Dane et al., 1968). La Fon (1981) has interpreted these sandy beds as offshore bar deposits. J. E. Fassett, U.S. Geological Survey (written commun., 1989) would

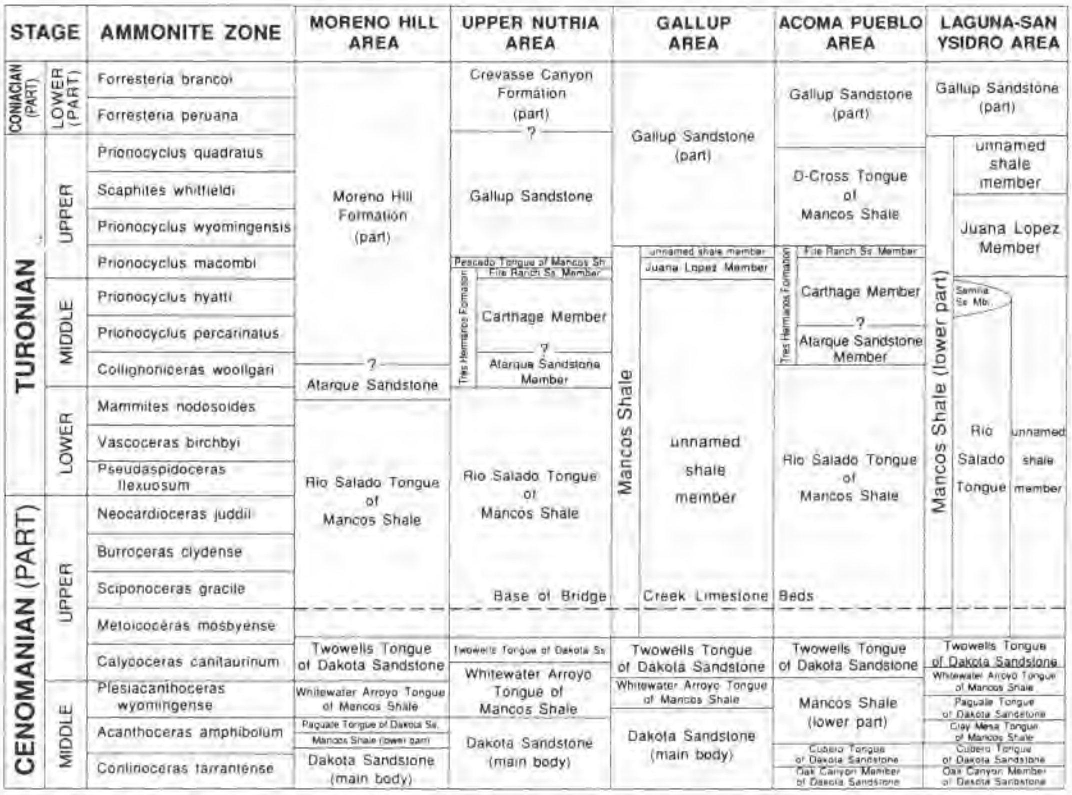

FIGURE 2. Stratigraphic nomenclature and correlation chart of mid-Cretaceous rocks in west-central New Mexico.

interpret them as shelf sandstones because they were so far offshore. The youngest marine lower Coniacian rocks in the area are represented by parts of the Gallup Sandstone. This unit, named by Sears (1925) for exposures at Gallup, is a regressive sandstone unit that becomes younger eastward. Molenaar (1973, 1974, 1983) has given a reference section and shown regional correlations.

Owing to facies changes across the area, a single set of stratigraphic names is not applicable to the entire field conference area. Figure 2 shows the nomenclature for five parts of the area and the relationship of the stratigraphic units to a time scale based on ammonites from this area as well as from other parts of New Mexico. The top of the Twowells Tongue of the Dakota Sandstone seems to be a persistent time line, but younger rock units generally rise in time in an eastward or northeastward direction. Most shorelines had a northwest trend (Sears et al., 1941; Pike, 1947; Molenaar, 1973, 1983; Cobban and Hook, 1984). The ammonite zonation shown in Figure 2 is modified after Cobban (1984a). The subzones of that report are omitted, and *Burroceras clydense* (Cobban et al., in press) is used in place of *Vascoceras cauvini*—a species that does not occur in New Mexico. In addition, two lower Coniacian zones of *Forresteria* are recognized.

MOLLUSCAN FOSSIL RECORD

The mid-Cretaceous rocks in west-central New Mexico contain an abundant molluscan record. Most fossils occur in concretionary sandstone beds or in calcareous concretions of sandstone, silstone or limestone. Coquinas are locally present. No attempt will be made here to list all of the species of fossils or to mention all the localities where collections have been made. Illustrations of the more important or more abundant species are shown in Figures 3–10. The illustrated specimens are kept at the National Museum of Natural History (formerly U.S. National Museum) in Washington, D.C., where they have USNM catalogue numbers. Plaster casts of a few of the specimens are at the U.S. Geological Survey in Denver, Colorado.

Oak Canyon Member of Dakota Sandstone

The Oak Canyon Member of the Dakota Sandstone was deposited in an embayment of the Western Interior sea in middle Cenomanian time. This embayment, named the Seboyeta bay, extended westward through west-central New Mexico almost to Gallup (Cobban and Hook, 1984, fig. 2). Molluscan fossils are abundant in the Oak Canyon Member, especially in the belt of outcrops that extends from near Acoma Pueblo northeastward to Seboyeta (Fig. 1). The fossils occur in dark-brown-weathering, calcareous, ferruginous concretions of siltstone and very fine-grained sandstone. At least 37 species of bivalves, 11 species of gastropods and 5 species of ammonites are known from the Oak Canyon Member in this area (Cobban, 1977, table 2). Fossils are usually mixed and fragmented in the concretions, which suggests some transport in a fairly high-energy environment (Fig. 3C, F). In a few concretions,

FIGURE 3. Molluscan fossils, natural size, from the Oak Canyon Member of the Dakota Sandstone. A, *Camptonectes symmetricus* Herrick and Johnson, USNM 239731, from USGS locality D5366 in the NE¼ sec. 29, T12N, R3W. B, *Turrilites acutus* Passy, USNM 239744, from USGS locality 3518 in the Rio Puerco valley. C, Latex cast of a slab of very fine-grained sandstone that contains *Plicatula arenaria* Meek (a), *Camptonectes symmetricus* Herrick and Johnson (b), *Granocardium* sp. (c), *Mediraon* sp. (d) and other bivalves, USNM 239636, from USGS locality D2053 in the NE¼ sec. 7, T8N, R7W. D, *Pholadomya* aff. *P. goldenensis* Stephenson, USNM 239728, from same locality as C. E, Latex cast of a slab of very fine-grained sandstone that contains many specimens of *Arrhoges modesta* (Cragin)?, USNM 239743, from USGS locality 5806 in the SW¼ sec. 21, T15N, R1W. F, Slab of very fine-grained sandstone that contains *Pinna petrina* White (a), *Exogyra columbella* Meek (b), *Plicatula arenaria* Meek (c) and *Conlinoceras tarrantense* Adkins (d), USNM 239614, from USGS locality D6794 in the NW¼ sec. 24, T7N, R8W. G, H, *Psilomya* aff. *P. concentrica* (Stanton), USNM 239729 and 239730, from USGS locality 5366 in the NE¼ sec. 29, T12N, R3W. I, J, *Exogyra columbella* Meek, USNM 239667, from USGS locality D2053 in the NE¼ sec. 7, T8N, R7W. K, Latex cast of a piece of very fine-grained sandstone that contains several left valves of *Exogyra aquillana* Stephenson, USNM 239676, from USGS locality D5815 in T16N, R1W. L, Slab of very fine-grained sandstone that contains numerous specimens of *Inoceramus* cf. *I. macconnelli* Warren, USNM 239621, from USGS locality D5756 in the NE¼ sec. 28, T15N, R12W.


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a single species occurs, which suggests little local transport (Fig. 3E, L). Gastropods, generally consisting of the single species *Arrhoges modesta* Cragin? (Fig. 3E), are so abundant in the Oak Canyon Member in the Rio Puerco valley, that Herrick (1900) and Lee (1912, 1917) referred to them as forming a conspicuous stratigraphic marker termed the "Gasteropod zone" or "Gastropod zone." Among the bivalves in the member, *Pinna petrina* White (Fig. 3F), *Inoceramus* cf. *I. macconnelli* Warren (Fig. 3L), *Exogyra aquillana* Stephenson (Fig. 3K), *Plicatula arenaria* Meek (Fig. 3C) and *Camptonectes symmetricus* Herrick and Johnson (Fig. 3A, C) are common and useful guide fossils. Ammonites are rather rare and known from one species each of *Desmoceras* (*Pseudouhligella*), *Conlinoceras*, *Borissiakoceras*, *Johnsonites* and *Turrilites*. The last is represented by an unusually coarsely tuberculate *T. acutus* Passy (Fig. 3B). The fauna of the Oak Canyon Member as well as that of the overlying Cubero Tongue of the Dakota Sandstone lies in the ammonite zone of *Conlinoceras tarrantense* (Fig. 2).

Cubero Tongue of Dakota Sandstone

Molluscan fossils are abundant in the lower part of the Cubero Tongue in the same general area (Acoma Pueblo-Seboyeta) where fossils are common in the underlying Oak Canyon Member. Cobban (1977, table 2) listed 18 species of bivalves from the Cubero Tongue, of which 16 are known also from the Oak Canyon Member. A small simple exogyra (Fig. 3K) is locally abundant in the middle and upper parts of the Cubero Tongue. A much larger, smooth exogyra also occurs in these parts of the member (Cobban, 1977, pl. 5, figs. 23–28). *Arrhoges modesta* Cragin? is the only gastropod known from the member. The only ammonites are occasional specimens of *Conlinoceras tarrantense* (Adkins) and *Turrilites acutus* Passy. The Cubero Tongue is in the ammonite zone of *Conlinoceras tarrantense* (Fig. 2).

Clay Mesa Tongue of Mancos Shale

Molluscan fossils are not common in the Clay Mesa Tongue. Only nine species of bivalves were listed by Cobban (1977, table 1); no gastropods were listed, and only three species of ammonites were given. *Pycnodonte* cf. *P. kellumi* (Jones) is probably the most common bivalve. *Inoceramus arvanus* Stephenson (Fig. 4K) seems to be confined to the member. Most of the remaining bivalves and all of the ammonites range up into the Paguate Tongue of the Dakota Sandstone. The Clay Mesa Tongue lies in the lower part of the ammonite zone of *Acanthoceras amphibolum* (Fig. 2).

Paguate Tongue of Dakota Sandstone

The Paguate Tongue of the Dakota Sandstone contains the greatest variety of molluscan fossils in west-central New Mexico. Cobban (1977, table 1) listed 25 species of bivalves, 27 species of gastropods and 10 species of cephalopods. Most fossils occur in sandstone concretions, where many of the shells are broken and reveal accumulation by the action of currents and waves (Fig. 4U). *Pycnodonte* cf. *P. kellumi* (Jones) (Fig. 4C–H) is abundant, and occasional specimens have retained their original color bands (Fig. 4F). *Exogyra trigeri* (Coquand), which first appeared in the Clay Mesa Tongue of the Mancos Shale, is a common species in the Paguate Tongue, where some specimens have attachment surfaces that reveal the kinds of mollusks on to which they were attached, such as the bivalve *Plicatula* or the gastropod *Turritella* (Fig. 4M). The thick-shelled bivalve *Phelopteria* cf. *P. aquilerae* Böse (Fig. 4S–T) is locally abundant. *Inoceramus rutherfordi* Warren is the dominant inoceramid bivalve; it is easily determined by its squarish outline and its fold in the shell (Figs. 4L, 5M); *Ostrea beloiti* Logan (Fig. 5C) is often attached to it. Gastropods are common (Fig. 4U) and of great variety. The presence of the ammonites *Acanthoceras amphibolum* Morrow (Fig. 5A, B) and *Plesiacanthoceres wyomingense* (Reagan) reveals the middle Cenomanian zones of *A. amphibolum* and *P. wyomingense* in the Laguna area. Other important ammonites include *Moremanoceras straini* Kennedy, Cobban and Hook (Fig. 4N–Q), *Tarrantoceras sellardsi* (Adkins) (Fig. 4R, 5I) and *Turrilites acutus* Passy (Figs. 4I, J, 5E).

Whitewater Arroyo Tongue of Mancos Shale

The Whitewater Arroyo Tongue of the Mancos Shale contains a considerable variety of molluscan fossils that occur either in the shale or in calcareous concretions. Among the fossils that are found in the shale are splendid specimens of *Exogyra trigeri* (Coquand) (Fig. 6M, N, P, Q). Attachment areas on some of these specimens reveal the former presence of bivalves such as *Granocardium trite* (White) (Fig. 6P) and the gastropod *Cerithiopsis* (Fig. 6D). Bivalves that range up from the underlying Paguate Tongue of the Dakota Sandstone include *Pinna petrina* White, *Plicatula* cf. *P. ferryi* Coquand (Fig. 6E–F), *Pycnodonte* cf. *P. kellumi* (Jones), *Exogyra levis* Stephenson, *Ostrea beloiti* Logan, *Granocardium enstromi* (Bergquist) and *G. trite* (White). The ornate bivalve *Idonearca depressa* White (Fig. 6A) first appears in the Whitewater Arroyo Tongue and ranges up into the overlying Twowells Tongue of the Dakota Sandstone. Nineteen bivalve species are known from the Whitewater Arroyo Tongue (Cobban, 1977, table 3). Only two species of gastropods are known, but eight species of ammonites are present. None of the ammonites is known below the Whitewater Arroyo Tongue, but four range up into the overlying Twowells Tongue of the Dakota Sandstone. Ammonites from the Whitewater Arroyo Tongue reveal that it ranges in age from the late–middle Cenomanian zone of *Plesiacanthoceras wyomingense* into the early–late Cenomanian zone of *Calycoceras canitaurinum* (Fig. 2).

Twowells Tongue of the Dakota Sandstone

Molluscan fossils from the Twowells Tongue of the Dakota Sandstone reveal that this unit lies in the zones of *Calycoceras canitaurinum* and *Metoicoceras mosbyense* of early–late Cenomanian age (Fig. 2). Cobban (1977, table 3) listed 22 species of bivalves, two species of gastropods and five species of ammonites from the member. Long-ranging bivalves found in the Twowells Tongue include *Idonearca depressa* Meek, *Pinna petrina* White, *Plicatula* cf. *P. ferryi* Coquand (some with color bands, Fig. 6G), *Exogyra trigeri* (Coquand), *E. levis* Stephenson and *Granocardium trite* (White). Inoceramids include *Inoceramus prefragilis* Stephenson (Fig. 6H) and *I. ginterensis* Pergament (Fig. 6O),

FIGURE 4. Molluscan fossils, natural size, from the Clay Mesa Tongue of the Mancos Shale (K) and the Paguate Tongue of the Dakota Sandstone (A–J, L–U). A–C, *Exogyra levis* Stephenson, USNM 239678, from USGS locality D5764 in the NE¼ sec. 30, T16N, R17W. D–H, *Pycnodonte* cf. *P. kellumi* (Jones); D, E, USNM 239656, from USGS locality D6182 in the NE¼ sec. 15, T4N, R20W; F, USNM 239658, from the same locality, shows radial color bands; G, H, USNM 239654, from USGS locality D7084 in the NE¼ sec. 20, T10N, R5W. I, J, *Turrilites acutus* Passy, USNM 239747 and 239746, from USGS locality D7328 in the NE¼ sec. 25, T15N, R12W. K, *Inoceramus arvanus* Stephenson, USNM 239630, from USGS locality D5380 in T17N, R1W. L, *Inoceramus rutherfordi* Warren, USNM 239628, from USGS locality D5750 in the SW¼ sec. 25, T15N, R12W. M, *Exogyra trigeri* (Coquand), USNM 239701, from USGS locality D6130 in the SW¼ sec. 6, T8N, R9W. N–Q, *Moremanoceras straini* Kennedy, Cobban and Hook, USNM 239753, from USGS locality D7328 in the NE¼ sec. 25, T15N, R12W. R, *Tarrantoceras sellardsi* (Adkins), USNM 239783, from near San Ysidro. S, T, *Phelopteria*? cf. *P. aguilerae* (Böse), USNM 239618, from USGS locality D4018 in sec. 29, T12N, R3W. U, Latex cast of a piece of fine-grained sandstone that contains the bivalve *Granocardium enstromi* (Bergquist) (a) and the gastropods *Turritella shuleri* (Stephenson)? (b), Helicaulax? sp. (c) and *Paleopsephaea* sp. (d), USNM 239725, from USGS locality D7345 in the SE¼ sec. 8, T15N, R13W.

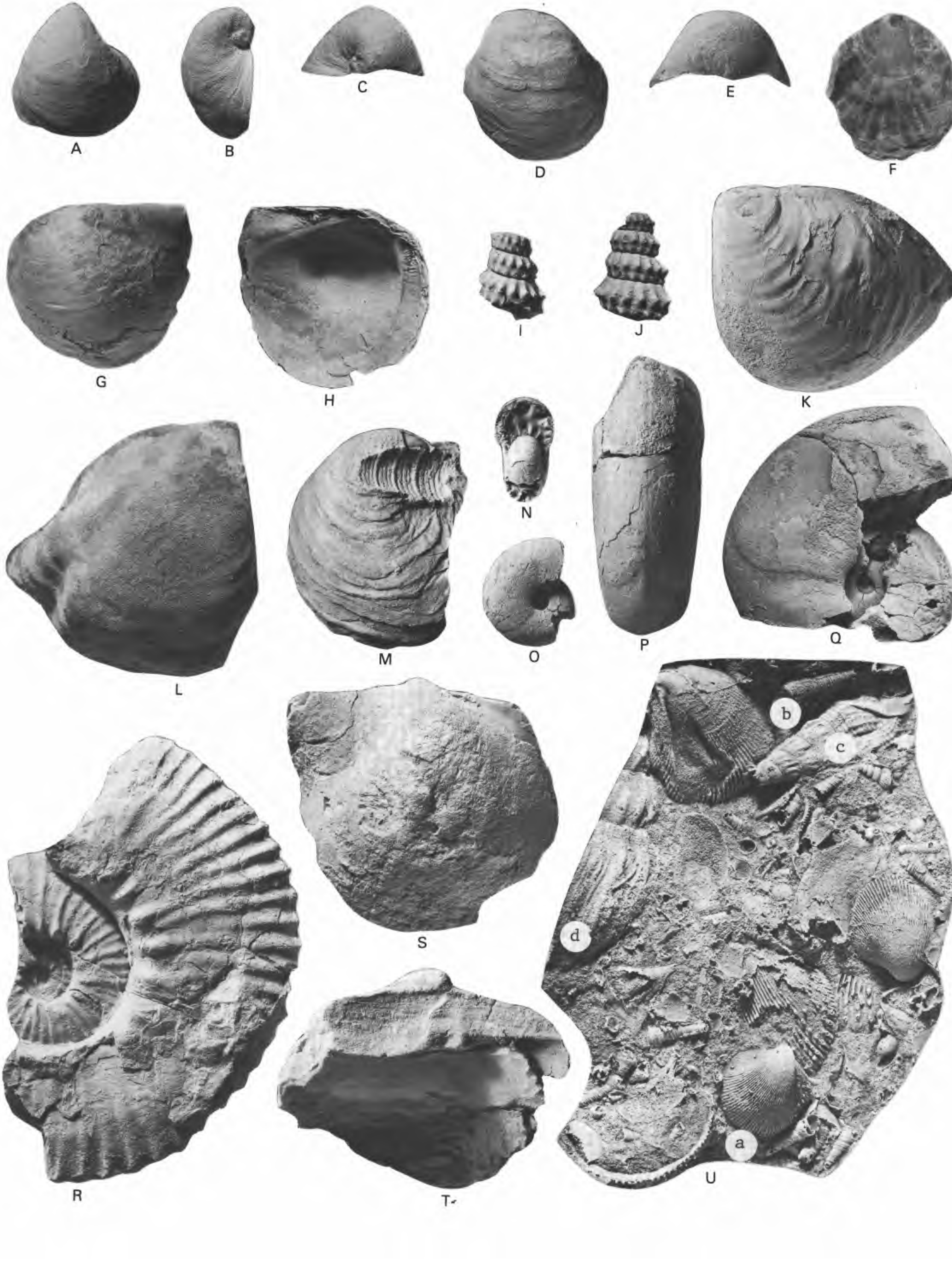
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FIGURE 5. Molluscan fossils, natural size, from the Paguate Tongue of Dakota Sandstone. A, B, *Acanthoceras amphibolum* Morrow, USNM 239770, from USGS locality D7328 in the NE¼ sec. 25, T15N, R12W. C, *Ostrea beloti* Logan, USNM 239715, from the same locality. D, *Granocardium enstromi* (Bergquist), USNM 239724, from USGS locality D7084 in the NE¼ sec. 20, T10N, R5W. E, *Turrilites acutus* Passy, USNM 239750, from the same locality as D. F, G, *Idonearca blanpiedi* Stephenson, USNM 239606, from the same locality as D and E. H, *Plicatula* cf. *P. ferryi* Coquand, USNM 239646, from USGS locality D7334 in the SE¼ sec. 32, T15N, R12W. I, *Tarrantoceras sellardsi* (Adkins), USNM 239760, from USGS locality D5380 in T17N, R1W. J, K, *Neithea* cf. *N. sexcostata* (Woodward), USNM 239741, from USGS locality D7332 in sec. 5, T14N, R12W. L, *Aphrodina* cf. *A. munda* (Stephenson), USNM 239737, from USGS locality D4018 in sec. 29, T12N, R3W. M, *Inoceramus rutherfordi* Warren, USNM 239629, from USGS locality D5750 in the SW¼ sec. 25, T15N, R12W. N, *Exogyra* cf. *E. oxyntas* (Coquand), USNM 239695, from USGS locality D7084 in the NE¼ sec. 20, T10N, R5W.

Pycnodonte aff. *P. kellumi* (Jones) (Fig. 6I–J) appears in great numbers. *Calycoceras canitaurinum* (Haas) and fragments of immature *Metoicoceras* (Fig. 6K–L) are the ammonites usually found, but neither is abundant.

Rio Salado Tongue of Mancos Shale

The Rio Salado Tongue of the Mancos Shale includes the marine shale that separates the Twowells Tongue of the Dakota Sandstone from either the Atarque Sandstone, the Tres Hermanos Formation or the Semilla Sandstone Member of the Mancos (Fig. 2). The Rio Salado Tongue ranges in age from early–late Cenomanian to middle Turonian. Its basal beds seem to be about the same age over all of west-central New Mexico, but the uppermost beds vary in age (Fig. 2). Molluscan fossils are abundant in some horizons, especially near the base and in the uppermost part. Thin limestone beds interbedded with calcareous shale are present near the base. These calcareous beds, which are equivalent to part of the Bridge Creek Member of the Greenhorn Limestone of the central Great Plains, are referred to as the Bridge Creek Limestone Beds in the belt extending from the Upper Nutria area eastward to San Ysidro and southward to the D Cross Mountain-Puertecito-Rio Grande area (Hook, 1983; Hook et al., 1983; Maxwell, in press). These beds, deposited in the widespread Greenhorn sea (Hook and Cobban, 1977, fig. 1), have also been referred to as the Greenhorn Limestone (Molenaar, 1977) and more recently as the Bridge Creek Limestone Member of the Mancos Shale (Kirk and Sullivan, 1987). One or more thin nodular beds of limestone at the base of the Bridge Creek Limestone Beds contains fossils indicative of the zone of *Sciponoceras gracile* of middle–late Cenomanian age. The most abundant bivalve is *Pycnodonte newberryi* (Stanton) (Fig. 7E–G), which usually occurs in great numbers (Hook and Cobban, 1977). The straight ammonite *Sciponoceras gracile* (Shumard) (Fig. 7S–V) is locally abundant. Other ammonites found in this zone include *Metoicoceras geslinianum* (d'Orbigny), *Pseudocalycoceras angolaense* (Spath), *Euomphaloceras septemseriatum* (Cragin) (Fig. 7O–P), *Allocrioceras annulatum* (Shumard) (Fig. 7J–K) and *Worthoceras vermiculus* (Shumard) (Fig. 7Q, R). All of these ammonites are widely distributed from Trans-Pecos Texas north to the Black Hills of South Dakota and Wyoming. Some of these species have great geographic distribution and are excellent international guide fossils. *Sciponoceras gracile* has been found in northern Mexico, southern England, northern France, southern Germany and possibly in Africa (Angola and Nigeria). *Metoicoceras geslinianum* is known in Mexico, England, France, Germany, Spain, Czechoslovakia, Israel, Iran(?), Angola, Nigeria and possibly Morocco. *Pseudocalycoceras angolaense* has been recorded in southern England, northern France, Angola and Japan. *Euomphaloceras septemseriatum* is known in California, northern Mexico, Brazil, southern England, northern France, Germany, Angola, Nigeria and Japan. Other fossils in the zone of *Sciponoceras gracile* include small echinoids, corals and several species of bivalves and gastropods. The *Sciponoceras* zone is fossiliferous everywhere and marks the basal beds of the Bridge Creek Member of the Greenhorn Limestone of the Great Plains and the equivalent rocks farther west.

Thin beds of calcarenite in the middle part of the Rio Salado Tongue contain abundant fragments of the lower Turonian bivalve *Mytiloides mytiloides* (Mantell) (Fig. 7H–I). This international guide fossil, often listed in the older literature as *Inoceramus labiatus* (Schlotheim), was originally described from the Middle Chalk of England (Mantell, 1822). *Mytiloides mytiloides* is abundant in the upper third of the Bridge Creek Member of the Greenhorn Limestone of the Great Plains region, where the species ranges throughout the lower Turonian ammonite zone of *Mammites nodosoides* and into the lower part of the middle Turonian zone of *Collignoniceras woollgari* (Fig. 2). *Mytiloides mytiloides* has been found at many localities in New Mexico (Cobban, 1984b).

A unique fauna of late–early Turonian age (zone of *Mammites nodosoides*) is present in the uppermost part of the Rio Salado Tongue in the Fence Lake area (Fig. 1) in the southwestern part of the field conference area (Cobban and Hook, 1983), where limestone concretions and thin beds of sandstone contain a variety of well-preserved bivalves, gastropods and ammonites. The concretions are mostly small and sometimes contain one to a few fossils, but some of the thin beds of sandstone may contain an abundance of shells (Fig. 8K). Nine bivalve genera have been recorded (Cobban and Hook, 1983, p. 5). The fauna is unique because the ammonites include a mixture of warm-water Tethyan forms and cooler water temperate species. The Tethyan forms are *Kamerunoceras turoniense* (d'Orbigny) (Fig. 8A–B), originally described from the early middle Turonian of Tourtenay, France; *Neoptychites cephalotus* (Courtiller) (Fig. 8G–H), originally described from Saumur, France; and *Fagesia superstes* (Kossmat) (Fig. 8I–J), originally described from southern India. Other warm-water ammonites that are not so widely distributed are *Morrowites depressus* (Powell) (Fig. 7X–Y), which is mostly confined to the southern part of the Western Interior and *Cibolaites molenaari* Cobban and Hook (Fig. 7M–N), which is known only from New Mexico and possibly in France and Germany. The cooler water forms include *Baculites yokoyamai* Tokunaga and Shimizu (Fig. 7A–B), *Placenticeras stantoni* Hyatt (Fig. 7W) and probably *Tragodesmoceras socorroense* Cobban and Hook (Fig. 7C–D).

Tres Hermanos Formation

The Tres Hermanos Formation is a northeastward-thinning wedge of clastic rocks that overlies the Rio Salado Tongue of the Mancos Shale (Fig. 2). The lowest unit, the Atarque Sandstone Member, is a regressive sandstone that is of early–middle Turonian age at most places, but it is partly late–early Turonian in the Fence Lake area in the southwestern part of the field conference area. Molluscan fossils are abundant locally in some of the sandstone beds, where disarticulated bivalves and fragmented ammonites reveal various degrees of transport by currents or waves (Fig. 9T). Species of *Cymbophora* and *Pleurocardia* are perhaps the dominant bivalves. Cobban and Hook (1979, p. 11) listed 19 genera of bivalves, seven genera of gastropods and six genera of ammonites from this member. Common ammonites are *Collignoniceras woollgari* (Mantell) (Fig. 9Q–R) and *Baculites yokoyamai* Tokunaga and Shimizu (Fig. 9P). *Spathites rioensis* Powell is fairly abundant locally in the Atarque Lake area (Cobban, 1988).

Molluscan fossils have not been found in the dominantly nonmarine Carthage Member that overlies the Atarque Sandstone Member. The Carthage Member is of middle– and early–late Turonian age (zones of *Prionocyclus percarinatus* into *P. macombi*) inasmuch as it grades into marine beds of that age in the northwestern part of the conference area (Hook et al., 1983, sheet 1).

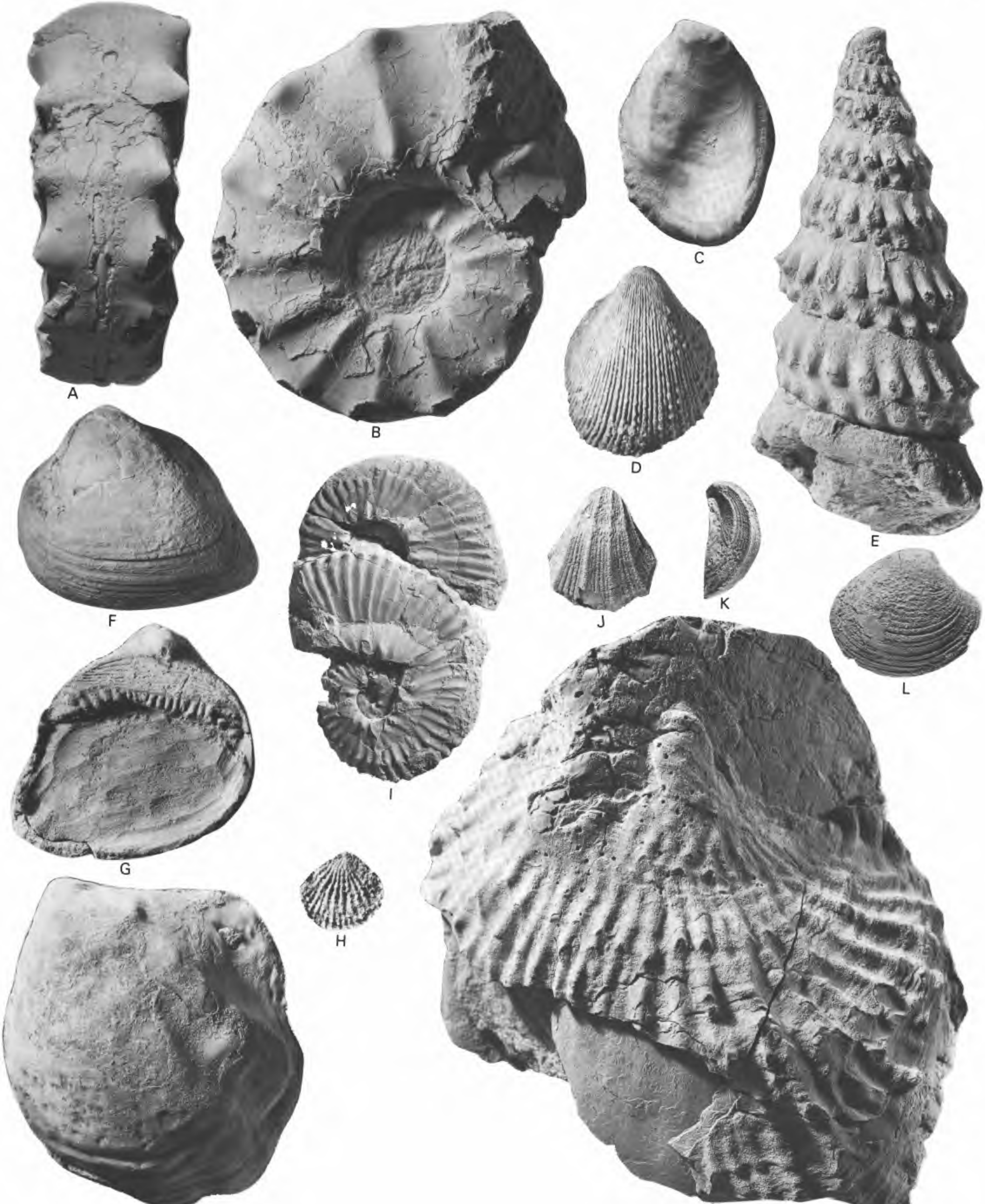
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FIGURE 6. Molluscan fossils, natural size, from the Whitewater Arroyo Tongue of the Mancos Shale (A, D–F, M, N, P, Q) and Twowells Tongue of Dakota Sandstone (C, D, G–L, O). A, *Idonearca depressa* White, USNM 239608, from USGS locality D5344 in the NE¼ sec. 29, T11N, R5W. B, C, *Granocardium trite* (White), USNM 239719, from USGS locality D6131 in the NE¼ sec. 4, T7N, R10W. D, *Exogyra trigeri* (Coquand), USNM 239705, from locality D7338 in the NW¼ sec. 8, T14N, R13W. E–G, *Plicatula* cf. *P. ferryi* Coquand; E and F, USNM 239639 and 239637, from USGS locality D6184 in the NW¼ sec. 15, T4N, R20W; G, USNM 239644, from USGS locality D7086 in the NW¼ sec. 21, T10N, R5W. H, *Inoceramus prefragilis* Stephenson, USNM 239631, from USGS locality D9240 in the SE¼ sec. 19, T14N, R20W. I, J, *Pycnodonte* aff. *P. kellumi* (Jones), USNM 239663, from USGS locality D6191 in the SW¼ sec. 2, T16N, R21W. K, L, *Metoicoceras* sp., USNM 239781, from USGS locality D6164 in the SW¼ sec. 7, T12N, R16W. M, N, P, Q, *Exogyra trigeri* (Coquand), USNM 239704 and 239711, from USGS locality D5759 in the SE¼ sec. 24, T15N, R13W. O, *Inoceramus ginterensis* Pergament, USNM 239634, from USGS locality D5392 in the SW¼ sec. 36, T19N, R1W.

The Fite Ranch Sandstone Member, which forms the top of the Tres Hermanos Formation, is a coastal-barrier transgressive sandstone that contains molluscan fossils of early–late Turonian age (zone of *Prionocyclus macombi*) (Fig. 2). Fossils are not abundant in the field conference area, but *Lopha bellaplicata* (Shumard) has been found at several localities, and Hook et al. (1983, sheet 1) listed that species together with *Lopha lugubris* (Conrad), *Inoceramus dimidius* White and *Prionocyclus macombi* Meek near Upper Nutria in the western part of the area.

Lower part of Mancos Shale

In the field conference area, the upper part of the Mancos is represented by the Mulatto and Satan tongues, which are not treated in this report. In areas where the Tres Hermanos Formation is not recognized, such as in the northern part of the field conference area from Gallup eastward to the Rio Grande (Fig. 1), the lower part of the Mancos Shale includes rocks from the top of the Twowells Tongue of the Dakota Sandstone to either the base of the Juana Lopez Member of the Mancos Shale or to the base of the Gallup Sandstone (Fig. 2). This shale includes rocks equivalent to the Rio Salado Tongue as well as some shale of younger age. In the Rio Puerco valley (Fig. 1), the lower part of the Mancos Shale includes the Semilla Sandstone Member, which carries a large and varied molluscan fauna (Dane et al., 1968). Fossils in this member as well as in the upper part of the underlying shale lie in the middle Turonian ammonite zone of *Prionocyclus hyatti*. The Semilla Sandstone Member contains a large and varied molluscan fauna (Dane et al., 1968). Well-preserved specimens of the bivalve *Lopha bellaplicata* (Shumard) are found, sometimes with attachment impressions of gastropods such as *Turritella* (Fig. 9S). Other common bivalves are *Inoceramus howelli* White (Fig. 9D), *Ostrea malachitensis* Stanton and species of *Trigonarca* and *Pleuriocardia*. Ammonites include *Prionocyclus hyatti* (Stanton) (Fig. 9I–J), *Hoplitoides sandovalensis* Cobban and Hook, *Coilopoceras springeri* Hyatt (Fig. 9K–L), and *Scaphites carlilensis* Morrow. Other ammonites in the zone of *Prionocyclus hyatti*, but below the Semilla Sandstone Member, include *Herrickiceras costatum* (Herrick and Johnson) (Fig. 9E–F) and *Spathites puercoensis* (Herrick and Johnson) (Fig. 9G–H). A little lower in the Mancos Shale are ammonites indicative of the lower–middle Turonian zone of *Collignoniceras woollgari* (Mantell) (Fig. 9Q–R).

Juana Lopez Member of Mancos Shale

Dane et al. (1966) gave a reference section for the Juana Lopez Member of the Mancos Shale about 12 km north of the northern boundary of the field conference area, where the member is about 41 m thick and consists of two ridge-forming units of calcarenite and shale separated by a much thicker shale unit. Molluscan fossils are abundant at the reference section locality, where they occur in shale, calcarenite and limestone concretions. There the Juana Lopez Member is of late Turonian age and spans the ammonite zones of *Prionocyclus macombi*, *P. wyomingensis* and *Scaphites whitfieldi*. The Juana Lopez Member extends southward into the northwesternmost part of the field conference area near Gallup (Hook et al., 1983) and southeastward through the Grants-Laguna area (Maxwell, 1982). Fossils are scarce and poorly preserved in the member in the Gallup area, but farther east in the area northeast of Thoreau, typical Juana Lopez fossils such as *Inoceramus dimidius* White, *Lopha lugubris* (Conrad), *Prionocyclus wyomingensis* Meek and *Scaphites whitfieldi* are common and well preserved.

Pescado Tongue of Mancos Shale

The Pescado Tongue of the Mancos Shale is present in the western part of the field conference area, where it is equivalent to part of the Juana Lopez Member farther north (Hook et al., 1983, sheet 1). We have seen only three molluscan species from the Pescado Tongue—*Inoceramus dimidius* White (Fig. 10T), *I.* cf. *I. flaccidus* White and *Lopha lugubris* (Conrad). These bivalves, which occur as internal molds in sandstone, are well preserved. The Pescado Tongue probably lies in the early late Turonian zones of *Prionocyclus macombi* and *P. wyomingensis*, but if the record of *P. hyatti* by Pike (1947, p. 34) is correct, the member may include some of the *P. hyatti* zone.

D-Cross Tongue of Mancos Shale

The D-Cross Tongue of the Mancos Shale is of late Turonian age and separates the Gallup Sandstone from the Tres Hermanos Formation (Fig. 2). Fossils are fairly abundant in limestone concretions and span the ammonite zones of *Prionocyclus wyomingensis*, *Scaphites whitfieldi* and *Prionocyclus quadratus*. The D-Cross Tongue is best developed in the D Cross Mountain-Puertecito area where characteristic fossils include *Inoceramus dimidius* White, *Lopha lugubris* (Conrad) (Fig. 10M), *Lopha sannionis* White (Fig. 10A–E), *Prionocyclus wyomingensis* Meek, *Scaphites warreni* Meek and Hayden, *Scaphites whitfieldi* Cobban (Fig. 10N–P) and *Prionocyclus quadratus* Cobban (Fig. 10H–I).

Gallup Sandstone

This regressive sandstone is diachronous, becoming younger in a northeastern direction (Fig. 2). In the western part of the field conference area, the Gallup Sandstone is of late Turonian age (zones of *Prionocyclus wyomingensis-P. quadratus*), whereas in the northeastern part, the formation is of early Coniacian age.

Molluscan fossils are locally plentiful in concretionary sandstone. Bivalves are the dominant forms. *Mytiloides incertus* (Jimbo), a late Turonian species, has been found in some areas. *Inoceramus longealatus* Tröger (Fig. 10F, G), of latest Turonian and earliest Coniacian age, has been found in the northeasternmost outcrops. Other early Coniacian inoceramids include *I. waltersdorfensis* Andert, *I. erectus* Meek, *I. rotundatus* Fiege and *I. inconstans* Meek. Well-preserved specimens of the plicate oyster *Lopha sannionis* (White) are abundant in places. This species has a range of late Turonian-early Coniacian and a geographic range from southern New Mexico to central–western Montana (Hook and Cobban, 1981, fig. 2).

Ammonites are not common in the Gallup. *Prionocyclus novimexicanus* (Marcou) and *P. quadratus* Cobban, both of late Turonian age, have been found at a few localities. The lower Coniacian ammonite *Forresteria peruana* (Brüggen) was found at one locality in the Rio Puerco valley; this ammonite has been known previously only from Peru.

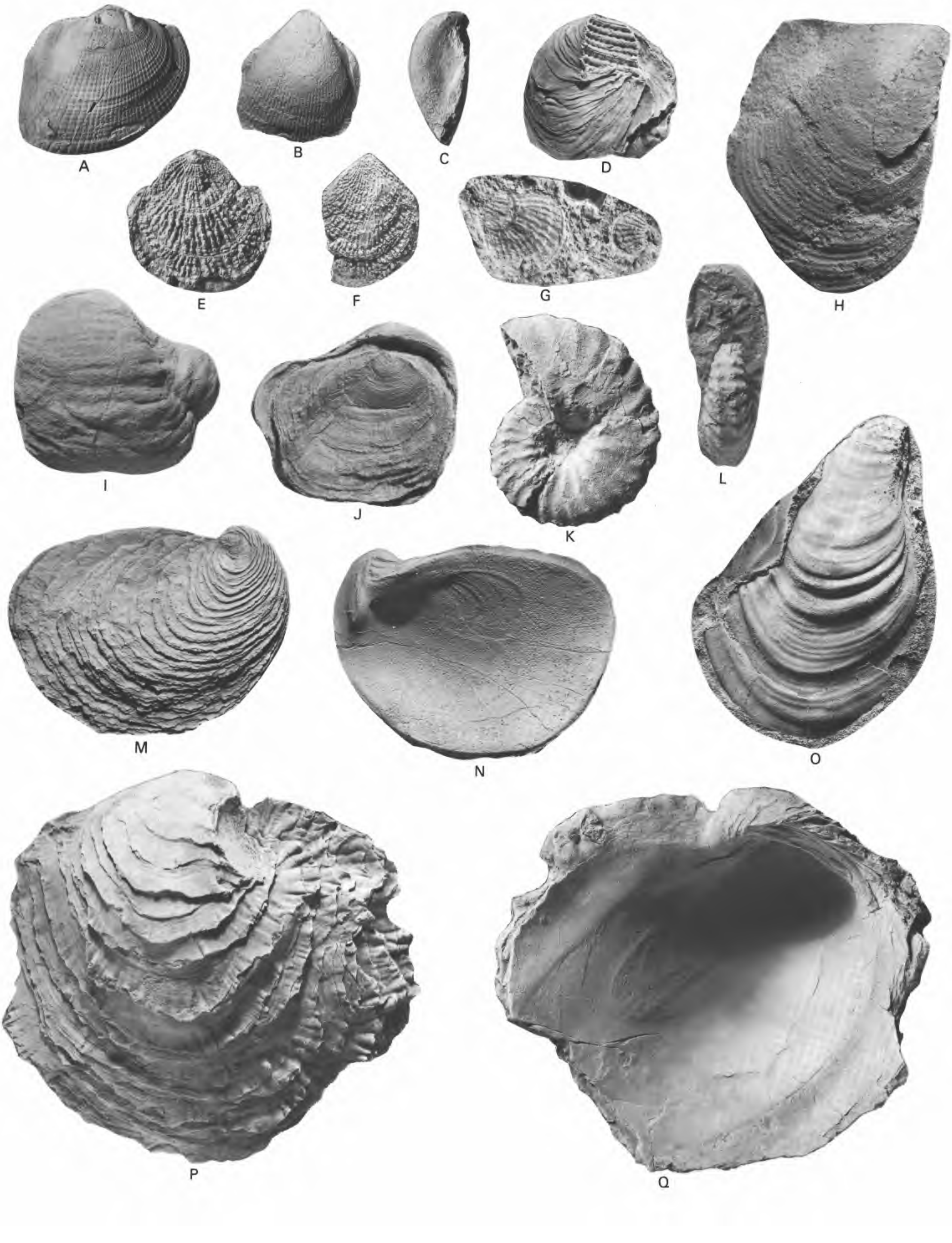
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FIGURE 7. Molluscan fossils, natural size, from the Rio Salado Tongue of the Mancos Shale. A, B, *Baculites yokoyamai* Tokunaga and Shimizu, USNM 328706, from USGS locality D8429 in the NE1/4 sec. 12, T4N, R19W. C, D, *Tragodesmoceras socorroense* Cobban and Hook, USNM 328707, from the same locality. E–G, *Pycnodonte newberryi* (Stanton), USNM 356887, from USGS locality D10264 in the NE1/4 sec. 36, T3N, R6W. H, I, *Mytiloides mytiloides* (Mantell), USNM 356888 and 356895, from USGS locality D10295 in the NW1/4 sec. 15, T2N, R5W. J, K, *Allocrioceras annulatum* (Shumard), USNM 356894, from USGS locality D10350 in the SE1/4 sec. 21, T2N, R4W. L, *Watinoceras cobbani* Collignon, USNM 252817, from USGS locality D10298 in the SW1/4 sec. 17, T3N, R8W. M, N, *Spathites rioensis* Powell, USNM 255606, from USGS locality D10472 in the SW1/4 sec. 34, T3N, R6W. O, P, *Euomphaloceras septemseriatum* (Cragin), USNM 356896, from USGS locality D10349 in the SE1/4 sec. 33, T3N, R5W. Q, R, *Worthoceras vermiculus* (Shumard), USNM 356898, from USGS locality D5798 in sec. 30, T2N, R3W. S–V, *Sciponoceras gracile* (Shumard), USNM 356899 and 356900, from USGS locality D10263 in the NE1/4 sec. 36, T3N, R6W. W, *Placenticeras stantoni* Hyatt, USNM 328709, from USGS locality D11208 in the NE1/4 sec. 36, T6N, R19W. X, Y, *Morrowites depressus* (Powell), USNM 252812, from USGS locality D10298 in the SW1/4 sec. 17, T3N, R8W.

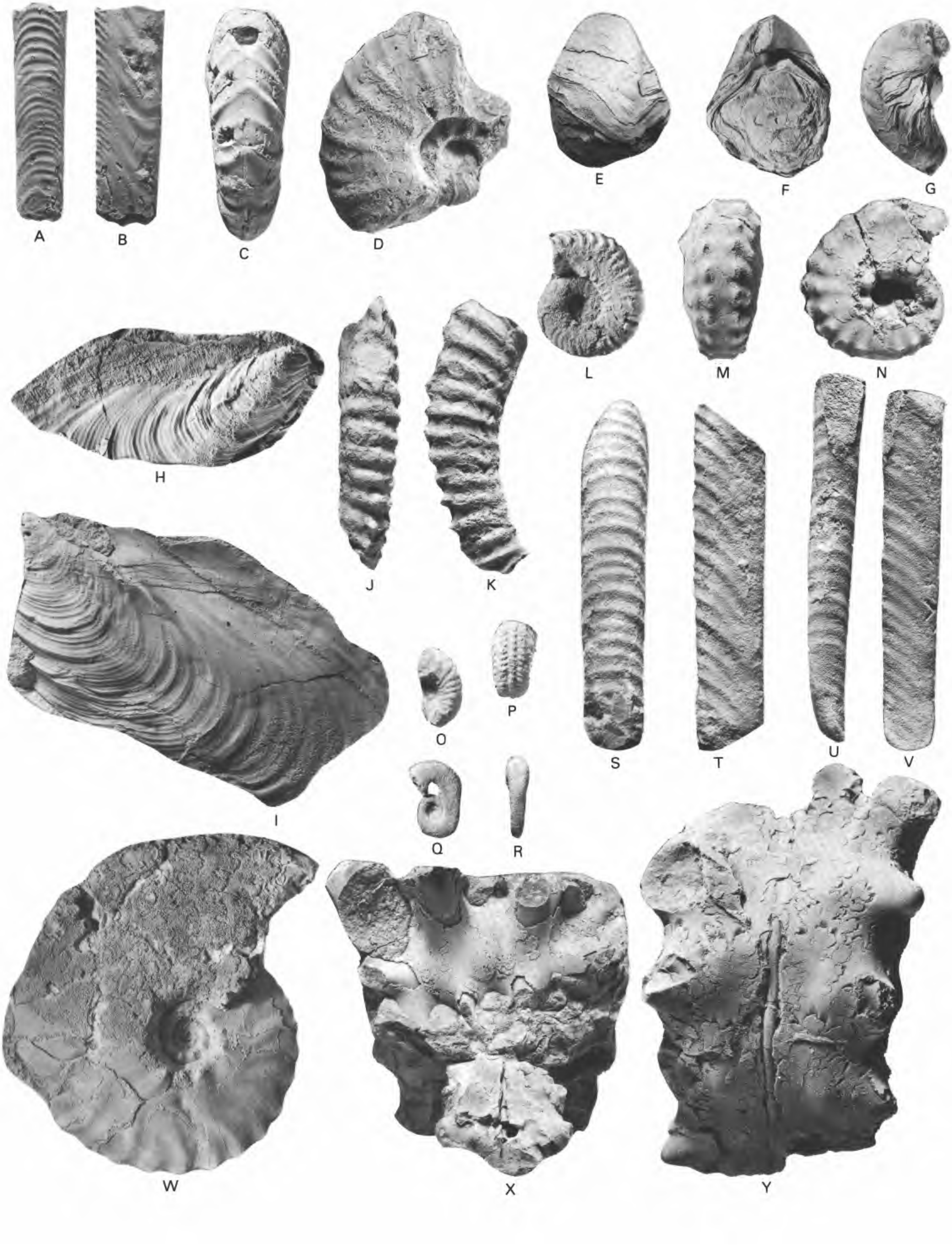
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FIGURE 8. Molluscan fossils, natural size, from the Rio Salado Tongue of the Mancos Shale. A, B, *Kamerunoceras turoniense* (d'Orbigny), USNM 328732, from USGS locality D11208 in the NE$^1/_4$ sec. 36, T6N, R19W. C, D, *Cibolaites molenaari* Cobban and Hook, USNM 356901, from the same locality. E, F, *Mammites nodosoides* (Schlüter), USNM 328718, from the same locality. G, H, *Neoptychites cephalotus* (Courtiller), USNM 328736, from USGS locality D8429 in the NE$^1/_4$ sec. 12, T4N, R19W. I, J, *Fagesia superstes* (Kossmat), USNM 328750, from the same locality as A–F. K, Piece of calcareous siltstone that contains abundant *Turritella whitei* Stanton, USNM 356902, from USGS locality D11706 in the E$^1/_2$ sec. 6, T6N, R19W.

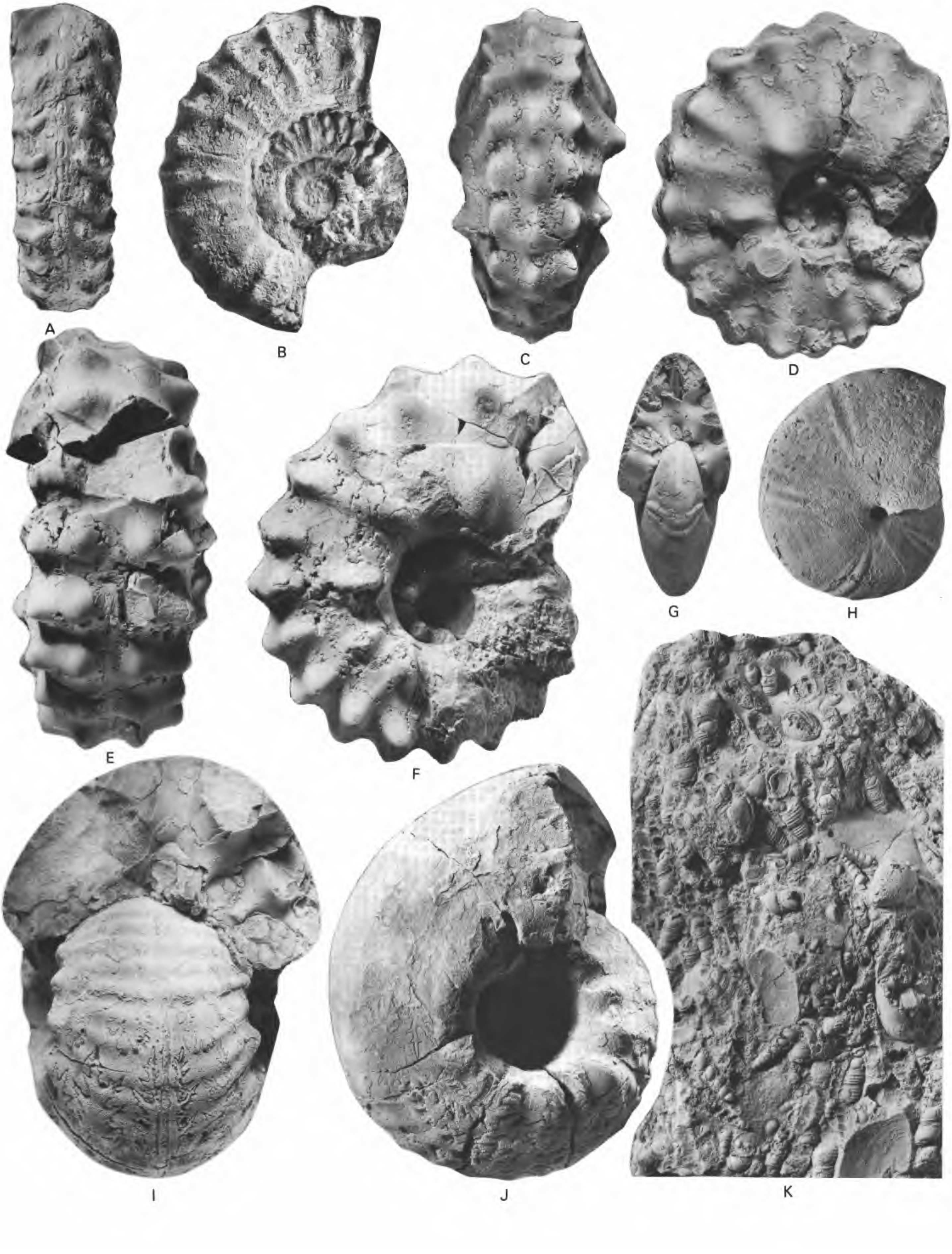
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FIGURE 9. Molluscan fossils, natural size, from the upper part of the Rio Salado Tongue of the Mancos Shale, the Tres Hermanos Formation, the Semilla Sandstone Member of the Mancos Shale and the basal part of the D-Cross Tongue of the Mancos Shale. A–C, *Coilopoceras colleti* Hyatt, USNM 275887, from the D-Cross Tongue at USGS locality D3702 about 3.8 km northwest of Ojito Spring, Sandoval County. D, *Inoceramus howelli* White, USNM 356903, from the Semilla Sandstone Member at USGS locality D10575 in the N1/2 sec. 6, T14N, R1E. E, F, *Herrickiceras costatum* (Herrick and Johnson), USNM 275941, from the Rio Salado Tongue at USGS locality D10469 in the Rio Puerco valley. G, H, *Spathites puercoensis* (Herrick and Johnson), USNM 321173, from the Rio Salado Tongue USGS locality 3672 in the Rio Puerco valley. I, J, *Prionocyclus hyatti* (Stanton), USNM 356904, from the Semilla Sandstone Member at USGS locality 28873 at Holy Ghost Spring, Sandoval County. K, L, *Coilopoceras springeri* Hyatt, USNM 275908, from the Semilla Sandstone Member at the same locality as I, J. M–O, *Hoplitoides sandovalensis* Cobban and Hook, USNM 275885, from the Rio Salado Tongue at USGS locality D10508 in the NW1/4 sec. 7, T12N, R2W. P, *Baculites yokoyamai* Tokunaga and Shimizu, USNM 252805, from the lower part of the Tres Hermanos Formation at USGS locality D10243 in the NE1/4 sec. 9, T5S, R2E. Q, R, *Collignoniceras woollgari* (Mantell), USNM 252784, from the lower part of the Tres Hermanos Formation at USGS locality D5773 in the NW1/4 sec. 24, T3N, R7W. S, *Lopha bellaplicata* (Shumard), USNM 356906, from the Semilla Sandstone Member at USGS locality 28875 at Holy Ghost Spring, Sandoval County. T, Piece of fine-grained sandstone that contains numerous specimens of *Cymbophora utahensis* (Meek) (a) and *C. emmonsi* (Meek) (b) as well as a fragment of *Collignoniceras woollgari* (Mantell) (c), USNM 356907, from the lower part of the Tres Hermanos Formation at USGS locality D10984 in the SE1/4 sec. 22, T8N, R17W.

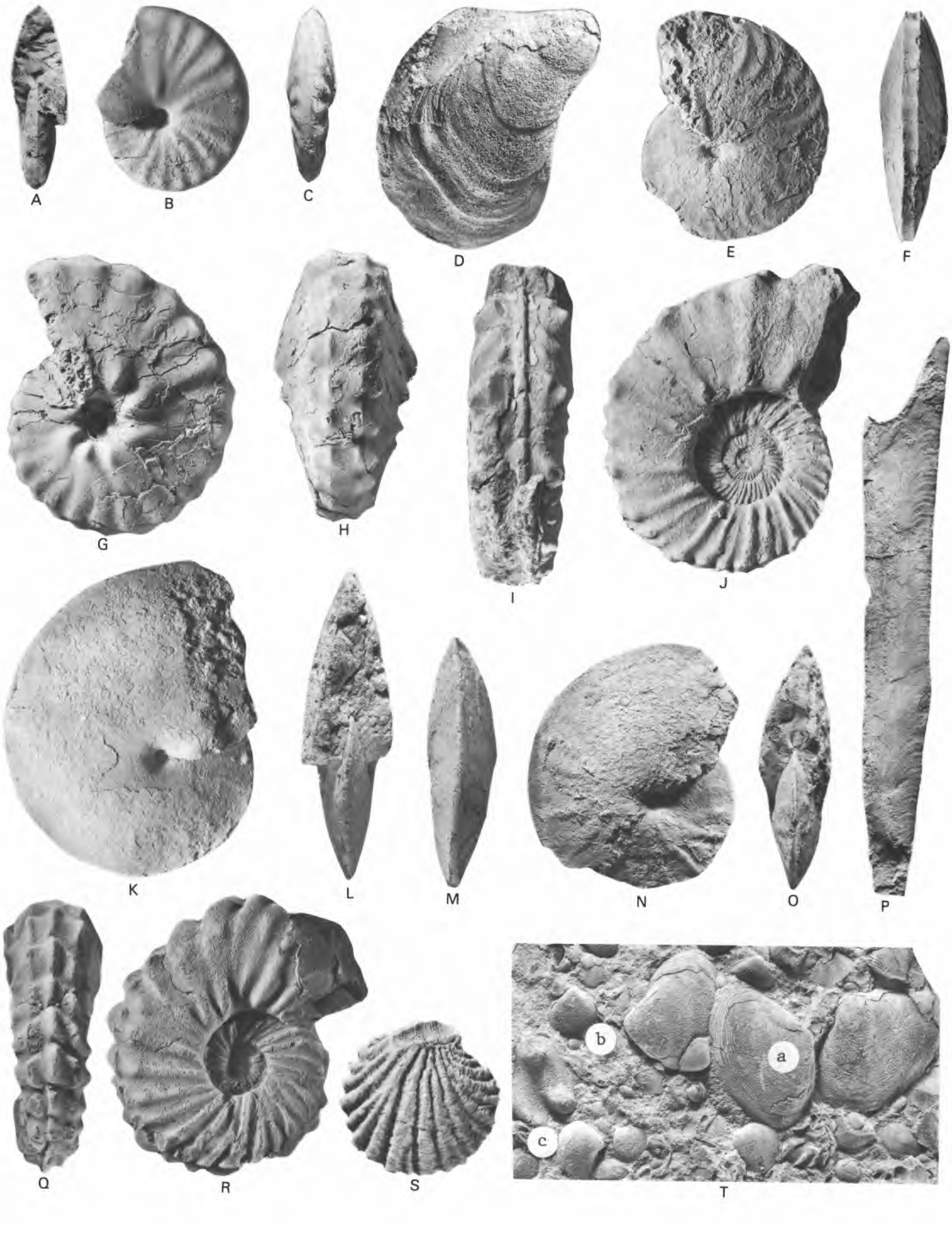
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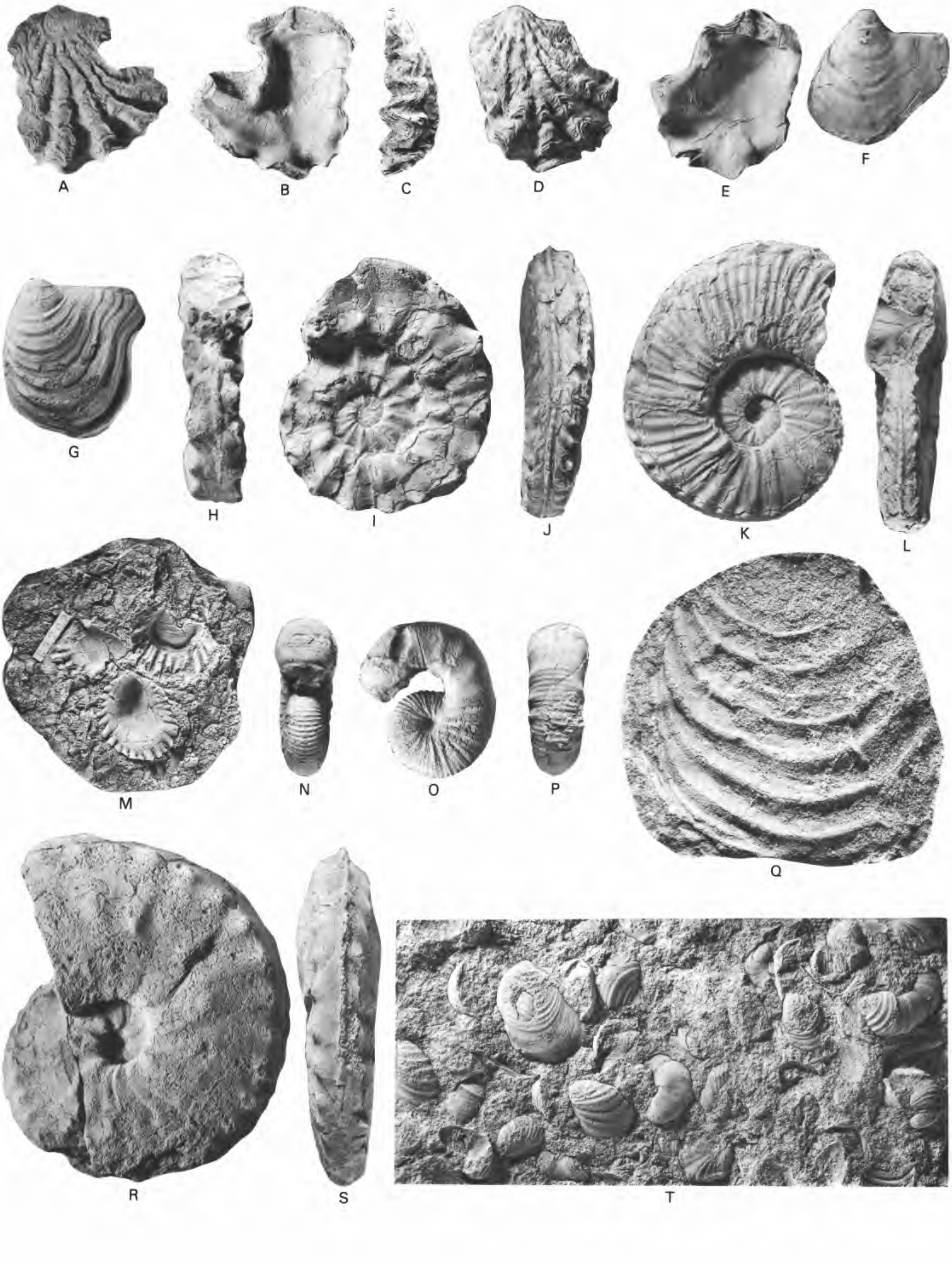
FIGURE 10. Molluscan fossils, natural size, from the Pescado and D-Cross tongues of the Mancos Shale and from the Gallup Sandstone. A–E, *Lopha sannionis* (White), USNM 356908 and 356909, from the D-Cross Tongue at USGS locality D10292 in the NE1/4 sec. 26, T2N, R4W. F, G, *Inoceramus longealatus* Tröger, USNM 356914 and 356916, from the D-Cross Tongue at USGS localities D10587 in the SW1/4 sec. 33, T16N, R13W and D4523 in the NW1/4 sec. 12, T11N, R3W. H–I, *Prionocyclus quadratus* Cobban, USNM 356918, from the D-Cross Tongue at USGS locality D10558 in the NE1/4 sec. 12, T2N, R5W. J–L, *Prionocyclus novimexicanus* (Marcou), USNM 356917, from the D-Cross Tongue at USGS locality D10969 in the NE1/4 sec. 31, T9N, R8W. M, *Lopha lugubris* (Conrad), USNM 356919, from the D-Cross Tongue at USGS locality D3702, 3.9 km northwest of Ojito Spring, Sandoval County. N–P, *Scaphites whitfieldi* Cobban, USNM 356920, from the D-Cross Tongue at USGS locality D10127 in the N1/2 sec. 7, T2N, R5W. Q, *Inoceramus rotundatus* Fiege, USNM 356921, from the Gallup Sandstone at USGS locality D10275 in the NW1/4 sec. 7, T2N, R5W. R, S, *Forresteria peruana* (Brüggen), USNM 356922, from the Gallup Sandstone at USGS locality 15932 in the SW1/4 sec. 1, T11N, R3W. T, *Inoceramus dimidius* White, USNM 283976, from the Pescado Tongue at USGS D10600 in the NE1/4 sec. 11, T10N, R17W.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