

## A new lithographic limestone deposit in the Upper Cretaceous Austin Group at El Rosario, county of Múzquiz, Coahuila, northeastern Mexico

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### ABSTRACT

*At El Rosario, 170 km WNW of Múzquiz in northern Coahuila, Mexico, alternating evenly layered platy limestone and fissile marly limestone of late Turonian-early Coniacian age (Late Cretaceous) contain vertebrate fossils with exceptionally well-preserved anatomical details of their soft tissues, as well as abundant ammonoids, inoceramids and other invertebrates. Deposition was in an open marine shelf environment near the southern opening of the Western Interior Seaway, several hundreds of kilometers south of the North American coastline, in water depths of at least 50–100 m. The present research intends to highlight the enormous preservational potential of this new conservation deposit (Konservat-Lagerstätte) and to analyze the paleoenvironmental conditions present at this locality. Our preliminary data suggest that the El Rosario fossil deposit is a combined result of anoxic bottom conditions, early diagenetic phosphatization, and rapid burial in a soft, micritic lime mud.*

*Key words: Upper Cretaceous, fossil preservation, Konservat-Lagerstätte, limestone, Coahuila, Mexico.*

### RESUMEN

*En El Rosario, aproximadamente a 170 km al WNW de Múzquiz, en la parte norte del Estado de Coahuila, México, una alternancia de calizas en laja y calizas margosas hojeadas de edad Turoniano tardío y Coniaciano temprano (Cretácico Tardío) contiene fósiles de vertebrados con preservación excepcional que incluye sus partes blandas, así como ammonoideos, inocerámidos y otros invertebrados. Los sedimentos se depositaron en un ambiente de plataforma marina abierta, a cientos de kilómetros de la costa sur del continente norteamericano, con profundidades del agua de por lo menos 50 a 100 m. En el presente trabajo se pretende demostrar el enorme potencial preservacional de este extraordinario depósito (Konservat-Lagerstätte). Nuestros datos preliminares sugieren que la excelente preservación*

*fossilífera en El Rosario es el resultado de una combinación de factores, entre ellos condiciones anóxicas en el fondo marino, una fosfatización diagenética muy temprana, y un enterramiento rápido en un lodo micrítico blando.*

*Palabras clave: Cretácico Superior; preservación de fósiles, Konservat-Lagerstätte, caliza, Coahuila, México.*

## INTRODUCTION

The present research is focused on the faunal association and paleoenvironmental conditions of the El Rosario quarry, located approximately 170 km WNW of Múzquiz in northern Coahuila, northeastern Mexico (Figure 1), near a rancho called La Rosaria. The sediments exposed in the quarry consist of limestone and marls of late Turonian to early Coniacian (Upper Cretaceous) age, which are best described by the German word *Plattenkalk*. The lithology corresponds to micritic, evenly layered, platy limestone, mostly with internal millimetric bedding (*Flinze*), and intercalated calcareous, fine-layered marls (*Fäulen*), similar to the Solnhofen Formation (Barthel *et al.*, 1990). Due to the platy rock fabric, the limestone forms slabs, which are intensively quarried for building facings, flagstones and

wall tiles.

During mining activities at El Rosario, vertebrate fossils are regularly excavated. These fossils often show an excellent state of preservation, for instance of fins and soft tissues. So far, in the Upper Cretaceous of northeastern Mexico, only the Vallecillo locality is known for a similar quality of preservation (Blanco *et al.*, 2001; Blanco-Piñon *et al.*, 2002; Blanco and Cavin, 2003; Ifrim *et al.*, in press). In contrast to Vallecillo, however, there is the potential of a type of phosphatization which preserves the softparts of fishes in three dimensions.

The El Rosario biota includes planktic foraminifers, ammonoids, bivalves, decapod crustaceans, fishes, marine reptiles (marine varanoids, crocodylians), a pterosaur, and remnants of terrestrial plants. The uniqueness and excellent preservation of the pterosaur certainly represents a first

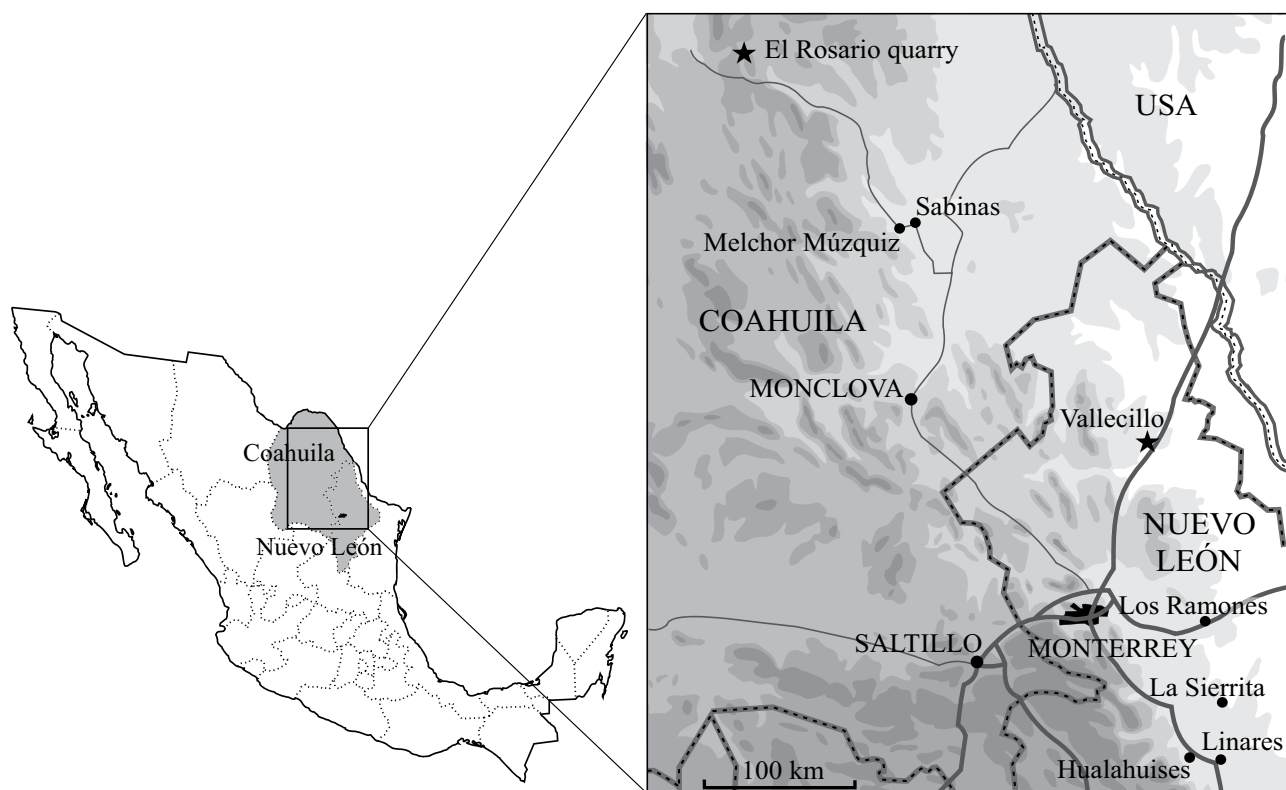


Figure 1. Location of important Upper Cretaceous *plattenkalk* localities in northeastern Mexico. Note that Vallecillo is located in the state of Nuevo León and El Rosario in the state of Coahuila.

highlight of the Múzquiz assemblage. The specimen belongs to the Nyctosauridae and represents a new genus and species (Frey *et al.*, in press).

With the exception of the pterosaur and marine varanoids (Buchy *et al.*, 2004, in press), none of the El Rosario fossils has yet been described in detail, and there are no publications describing the locality and its genesis. Here we document the extraordinary fossil potential of this new Cretaceous *Konservat-Lagerstätte* in northeastern Mexico.

The present survey forms part of a scientific collaboration between the Museo del Desierto (MUDE) at Saltillo, the Facultad de Ciencias de la Tierra of the Universidad Autónoma de Nuevo León, at Linares (FCT), the Asociación de Paleontólogos Aficionados at Sabinas (PASAC), the Geology Department of the Staatliches Museum für Naturkunde at Karlsruhe (SMNK), and the Institute of Regional Geology at the University of Karlsruhe (UKRG) in Germany. Since March 2002 we have investigated the sediments and faunal assemblage at El Rosario and similar coeval localities north of Múzquiz. The majority of fossil fish specimens are in private collections, so we plan to launch systematic fossil collections at El Rosario and other nearby quarries in the near future. We intend to develop a fossil inventory and to establish the precise biostratigraphic age of the sediments and paleoenvironmental conditions that permitted the genesis of this extraordinary fossil deposit. Currently, the faunal assemblage is being investigated at the SMNK and UKRG in Germany; subsequently, fossils will be placed in the collection of the MUDE in Mexico. Holotypes such as the pterosaur will be placed in the paleontological type collection at the UNAM, in Mexico City (UNAM IGM 8621).

### Geographic location

The town of Múzquiz is located in the northeastern Mexican state of Coahuila, approximately 300 km north of Saltillo and 100 km north of Monclova (Figure 1). Múzquiz is a mining center for much of northern Coahuila and the main commercial center for white and yellow limestone flagstones quarried in the region to the north. The principal mining area is in a semiarid region with few isolated houses and farms that can be reached by a single dirt road that branches off main road 53 between Múzquiz and Boquillas del Carmen at approximately 110 km. Several limestone quarries are operating in this remote region. Our study concentrates on the El Rosario quarry, which is located approximately 170 km NW of Múzquiz, at Lat 28°52.587'N, Long 102°24.216'W (Grid NAD 27), and from which the near-complete pterosaur and remnants of marine reptiles were excavated. This quarry, located at an average altitude of 1,350 m above sea level, exposes a carbonate sequence that is about 50 m thick, over an area of about 150 m x 300 m. Volcanic rocks (rhyolites, ignimbrites) of probable

Neogene age disconformably overlie the Cretaceous limestone sequence and form surrounding mountains rising to 1,540 m above sea level (Figure 2a).

### GEOLOGICAL SETTING

In the El Rosario quarry, limestone and marls that are likely part of the Upper Cretaceous Austin Group are exposed. This widespread unit of marls and limestone is widely distributed in northeastern Mexico and southern Texas, but is generally relatively unfossiliferous (Sohl *et al.*, 1991). The Austin Group sediments were deposited under open marine conditions, and Sohl *et al.* (1991) considered this unit to be Coniacian–Campanian in age, whereas Goldhammer and Johnson (2001) placed the Group in the late Turonian to Santonian. Neither the base nor the top of the Austin Group is exposed at El Rosario.

### The sediment

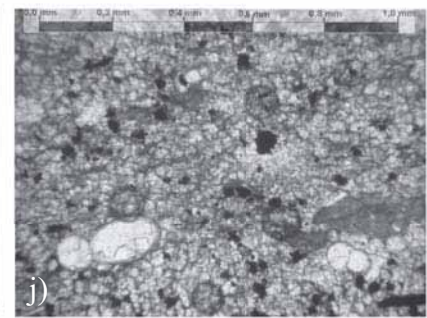
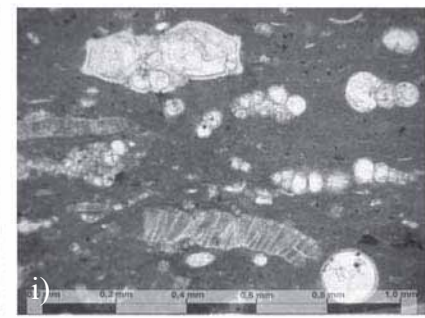
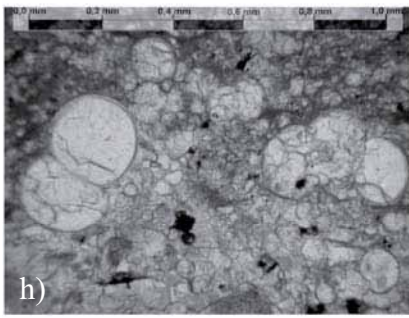
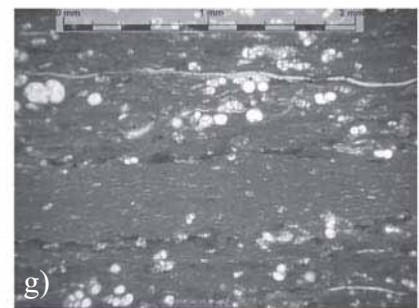
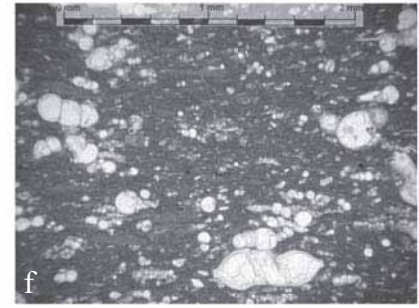
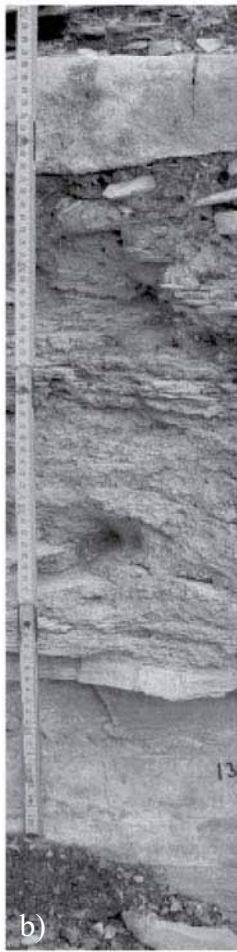
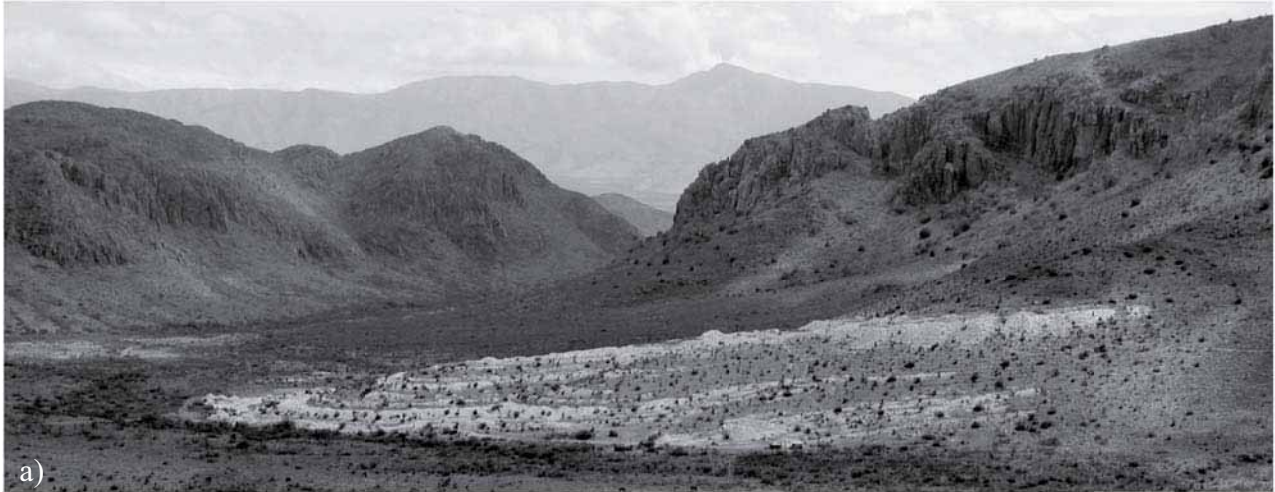
The sediment sequence is monotonous and consists of evenly layered platy limestone and interlayered millimetrically-layered marls (Figure 2b–d). The limestone layers are micritic mudstones, wackestones and packstones with shell hash. Dismicrite or microsparite only occur occasionally as the result of diagenetic overprint (Figure 2e–g). This limestone is between a few tens of mm and more than 0.5 m thick, massive or millimetrically laminated, and resistant to weathering. Carbonate content of the limestone is always higher than 95%. The interlayered marl units reach thicknesses of 1 m or more and are more susceptible to weathering than the limestone.

Planktonic foraminifers represent abundant bioclasts (Figure 2e–i), whereas calcispheres, ostracods, or fragments of macrofossils (*e.g.*, inoceramids, fish remains) only occur occasionally. For the most part, these bioclastic grains form thin layers that contribute to the primary millimetric lamination of the sediment.

Biodeformation structures or distinct trace fossils are very rare at El Rosario and restricted to a few isolated and thin sediment layers. For instance, *Chondrites* feeding structures have only been recognized in layer 23, at 12.5 m and possible burrows of *Thalassinoides* appear to be restricted to layer 45, at 28m. In addition, indistinct horizontal tracks or trails presumably produced by invertebrates are present in the limestone layers at 12.5 m and at 32 m in the section. Bioturbation is not observed in any of the other sediments in the section.

The limestone sequence has been divided into three lithologic units (members) on the basis of the thickness of their layers, color of the rocks, and grade of lamination:

The basal *gray member* (Figure 2b), base not exposed (Figure 3), is 18.5 m thick. Sediments are gray colored, slightly to intensively laminated and only occasionally flaser



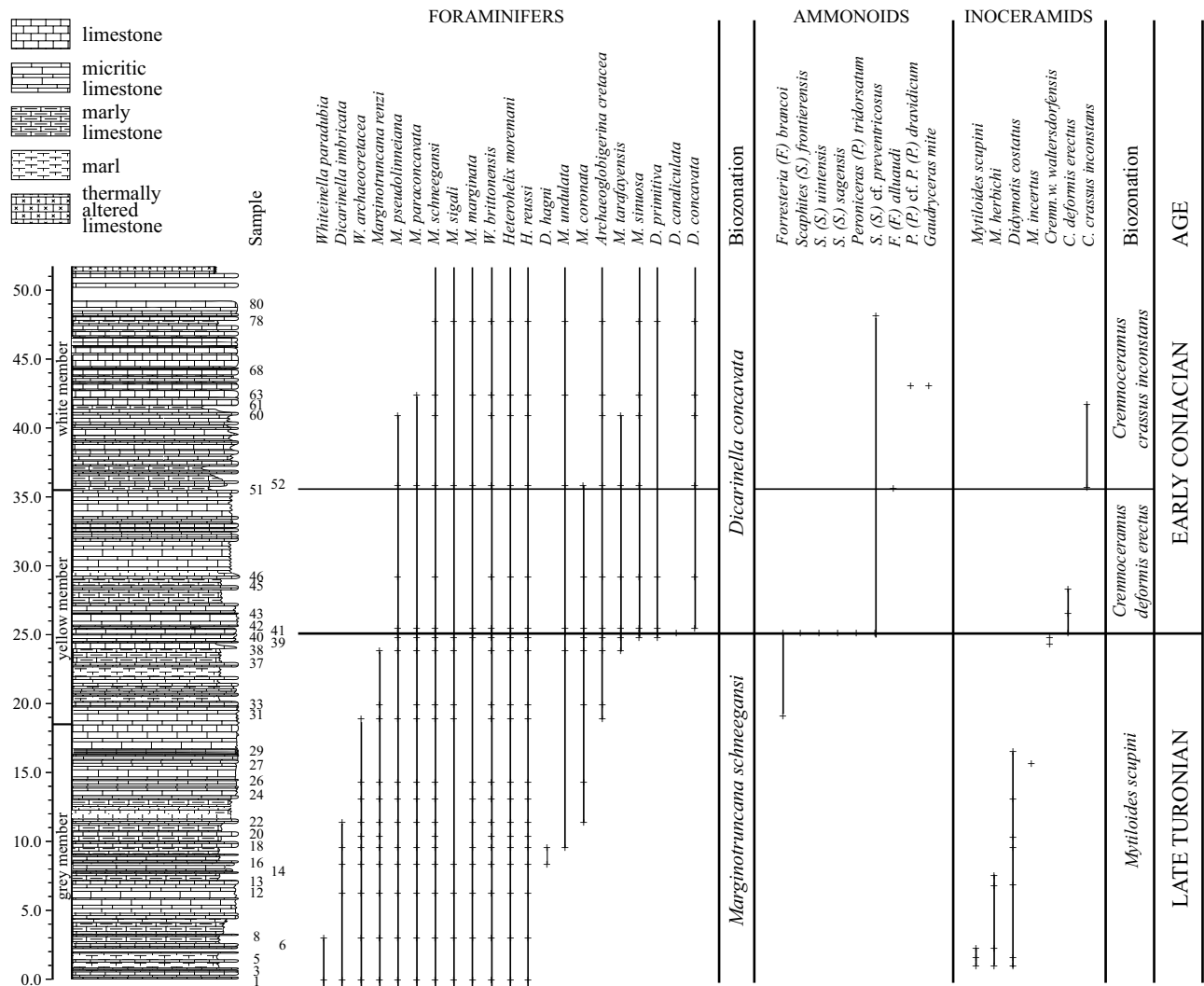


Figure 3. Stratigraphic column of fossiliferous limestone and marls at El Rosario, including the stratigraphic distribution of lithostratigraphic units and important planktic foraminiferal, inoceramid and ammonite species. Zonation is based on inoceramids and indicates a late Turonian–early Coniacian age of the sediments. Note that three lithostratigraphic members are differentiated on the basis of the color of rocks and degree of lamination.

bedded. Limestone layers are between 0.1 and 0.5 m thick and frequently contain inoceramid shell hash (Figure 2e) and complete shells, ammonoids and fish scales. Several layers are bituminous and expel a fetid smell when broken with a hammer. This limestone alternates with units of up to 1.10 m thickness of thin-bedded, sheet-like to platy marls and marly limestone, with thicknesses of individual layers

between 2 and 20 mm. The gray member may correspond to the “grayish massive limestone” (Sohl *et al.*, 1991, p. 223), that Young (1985) reported as forming the base of the Austin Group in the classical type area of central Texas.

The middle *yellow member* (Figure 2c) is 17 m thick and is characterized by yellow to light gray sediment colors, intensive millimetric lamination, and true lithographical

Figure 2. a: General view of the El Rosario area. Note that light-colored limestone of the El Rosario *plattenkalke* dips to the S with an angle of approximately 5°. Brown to rust-colored mountains around the El Rosario quarry consist of volcanic rocks of probable Neogene age which disconformably overlie the Cretaceous limestone sequence. b – d: Typical rocks of the El Rosario limestone quarries. Note that the sequence consists of platy limestone forming resistant layers and intercalated less resistant fissile marls and marly limestone. Lithologies are intensively laminated. b: Layers R13–R14 from the lower “gray member”. c: Layers 42–43 of the middle “yellow member”. d: Layers R75–77 of the upper “white member”. See meter and hammer for scale. e–j: Typical microfacies of the El Rosario limestone. Note that sediments are planktic foraminiferal mudstones and packstones; fossil grains accentuate lamination of the sediments. e: Layer R5; f: Layer R10; g: Layer R31; h: Layer R1; i: Layer R12; j: Layer R35.



rock textures, with limestone (*Flinz*) and marl (*Fäule*) alternances (Barthel *et al.*, 1990). The contact between the basal and the middle member is characterized by a change in sediment color from gray to yellow-buff and by the first appearance of a true lithographical lithology. Resistant limestone layers are up to 0.5 m thick and are interlayered with units up to 1.40 m thick of fissile to platy marls and marly limestone. The upper half of the yellow member is characterized by an increase in limestone, light gray to buff colors, and more wavy and less laminated textures.

The upper *white member* (Figure 2d) comprises white to light gray, resistant limestone of up to 0.5 m in thickness, with interlayered platy limestone of 10–30 mm thickness, forming units up to 2 m. The transition between the yellow and the white member is gradual. Towards the upper part of this member, fissile marls become gradually less abundant and disappear completely. Also within the unit, rocks have wavy surfaces indicating pressure solution during late diagenesis, and are faintly laminated or massive. The white member disconformably underlies rhyolitic volcanic rocks of probable Neogene age (Figure 3).

### Diagenesis

The pale color of the El Rosario limestone and marls presumably results from secondary bleaching and oxidation during late diagenesis, which led to the degradation of kerogen. Originally, the fine-grained sediment was probably rich in organic matter. This is indicated by organic matter in some layers of the gray member and by occasional thin laminae and some thick horizons with concretions of goethite that occur throughout the section. The goethite is the result of the oxidation of primary pyrite. The good preservation of fossils and the almost complete absence of bottom dwelling organisms, except for inoceramids, is a consequence of dysoxic to anoxic conditions in the bottom waters and supports the hypothesis that the original sediment must have been rich in organic matter.

### FAUNAL ASSEMBLAGE

To date, the faunal elements collected at El Rosario consist of approximately 200 specimens of ammonoids, decapod crustaceans, bivalves, fishes, remnants of marine reptiles, and a pterosaur. Only the pterosaur, the varanoids and a few invertebrates have been identified preliminarily. Their formal description is presently under way (Buchy *et al.*, 2004, in press). Our collection of specimens is the result of a systematic ten-day fossil excavation and geological survey in March 2004, and several random surveys done by a quarry worker during the second half of 2003 and beginning of 2004. Because of the brevity of our work, we are convinced that a realistic estimate of the biodiversity cannot be given today and that future collections at El Rosario will

significantly increase the number of taxa.

### Vertebrates

#### *Preservation of vertebrates*

The vertebrate assemblage consists of complete and disarticulated specimens, as well as primary fragments of vertebral columns, fins, single isolated bones, scales, etc. They seem to be randomly distributed in the sediment. Skeletons are embedded laterally, sometimes in dorsoventral position.

Many skeletons of our collection are fully articulated, and disarticulated skeletal elements of fishes and other vertebrates appear to be a result of decay during post-mortem floating. At present there is no evidence for major current transport on the sea floor.

Most vertebrate fossils are compressed, as a consequence of the compaction of the sediment. Some specimens are preserved in 3D, although flattened. In several of these specimens, geopetal collapse is observed. In general, compressed specimens are embedded parallel to the lamination. Delicate morphological elements (*e.g.*, fin rays, gill rakers and filaments) of some specimens are obliquely embedded, indicating that the sediment must have been soft (Martill, 1993a).

According to microprobe analysis, bones are frequently preserved as fluorapatite. Phosphatization of soft parts such as intestinal contents, myotomes, gill filaments, cycloid scales and fins of fishes, is observed occasionally and indicates that replacement of organic tissues by fluorapatite occurred at a very early stage of diagenetic mineralization, preceding or accompanying microbial decay, and often prior to sediment compaction. This process of a very early and almost instantaneous phosphatization has been described as a medusa effect by Martill (1993a).

### Fishes

Selaceans and osteichthyans have been shown to us by quarrymen and private collectors. These fishes have apparently been collected randomly at El Rosario and other quarries in the area from coeval sediments of the same depositional regime. The following taxa have been tentatively identified by one of us (L.C.) on the basis of photographs: *Ptychodus* cf. *P. mortoni* Agassiz, 1843 (Figure 4a); Elasmobranchii indet.; cf. *Scapanorhynchus* (Lamniformes); Acanthomorpha indet. (Figure 4b); Ichthyodectiformes indet.; Tselfatiiformes indet.; ?Cimolichthyoidei indet. (Figure 4c-f); ?Enchodontoidei indet.; ?Prionolepididae indet. Pycnodontiformes are also present at El Rosario (WS and EF, pers. observ.). Teleosteans are the most abundant elements of the El Rosario fish assemblage and are represented by both primary fragments and complete specimens.

Our taxonomical determination of the El Rosario fish assemblage is far from certain at present and cannot be used for paleobiogeographical conclusions. However, this as-

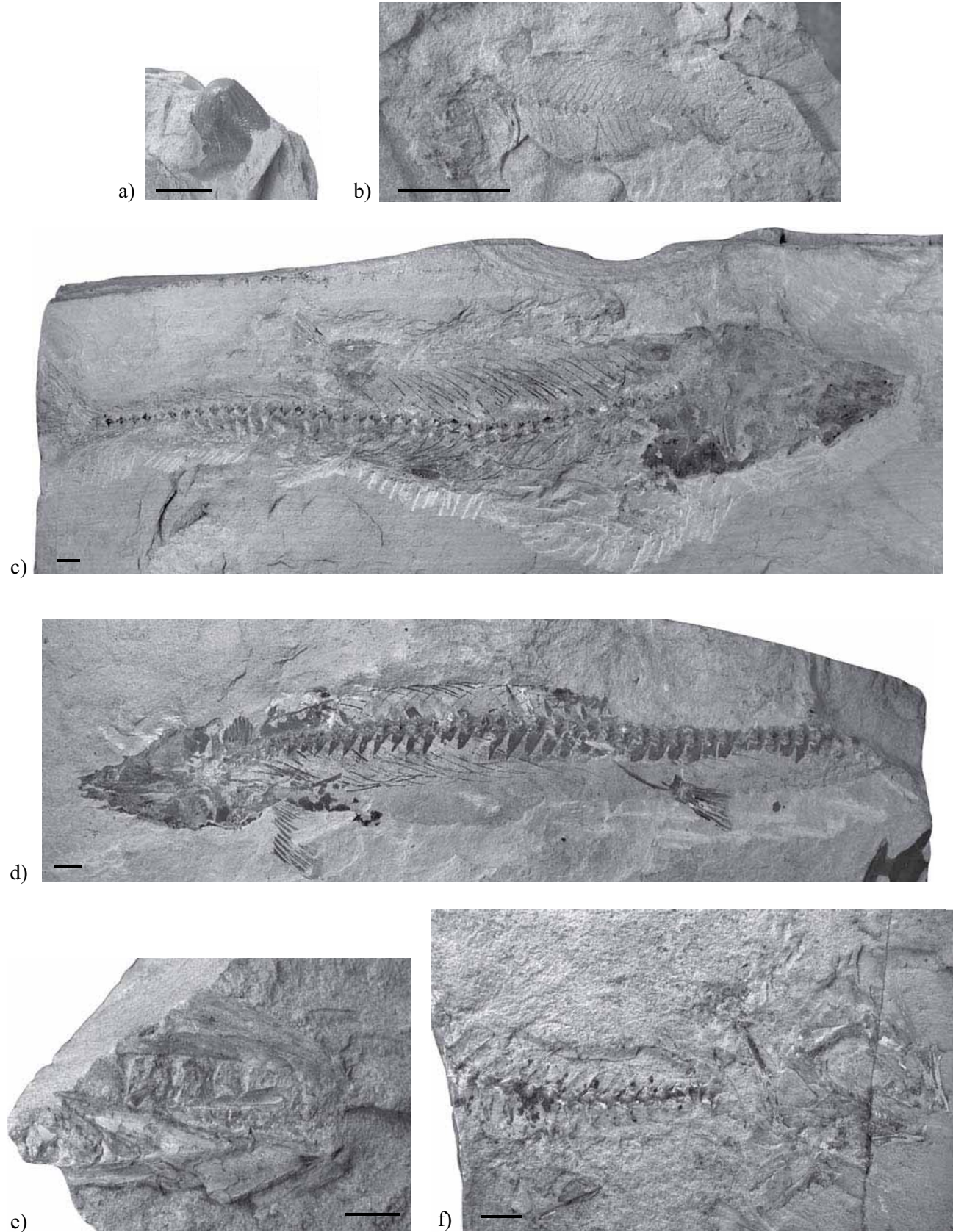


Figure 4. a: Isolated tooth of *Ptychodus* sp.  $\times 1$ . b: *Acanthomorpha* indet.  $\times 2$ . c-f: *Cimolichthyoidei* indet. c:  $\times 0.4$ . d:  $\times 0.5$ . e:  $\times 1$ . f:  $\times 0.75$ . Scale bars 10 mm.

semblage potentially fills a geographic and stratigraphic gap between several assemblages known from the Cenomanian of the Tethys, *e.g.*, at Jebel Tselfat in Morocco (Arambourg, 1954) and Hakel, Hajula and Namoura in Lebanon (Forey *et al.*, 2003), and the Late Cretaceous assemblages of the US and Canadian Western Interior Sea (see Russell, 1988 for a check list). The presence of tselfatiiforms is worth noting: Tselfatiiforms are rare and bizarre fishes represented in North Africa and Europe by *Tselfatia formosa* Arambourg, 1954 (Taverne, 2000), and by an endemic radiation of more than ten genera in the Western Interior Sea (Taverne and Gayet, 2005). *Tselfatia formosa* is surprisingly one of the most common fishes in the basal Turonian locality of Vallecillo, northeastern Mexico (Ifrim *et al.*, in press). The tselfatiiforms from El Rosario could not be identified at the generic or specific level yet, but they are obviously not *T. formosa*. The El Rosario taxon could turn out to be a key species for understanding the evolutionary history of the group.

### Marine reptiles

One isolated poorly preserved vertebra belongs to an undetermined crocodylian of about 2.5 m in length (specimen PAS 629). An isolated procoelous vertebral centrum (specimen PAS 337, Figure 5a-d) shows inclined articular surfaces and depressed condyle and cotyle. The absence of hypapophyses and the presence of transverse processes indicate a vertebra from the cranial portion of the tail, possibly from Varanoidea. Some features of the centrum suggest an aquatic animal (Rage, 1989; Buchy *et al.*, 2004, in press), although the fragmentary nature of the specimen prevents a more precise identification.

Two articulated vertebral centra are preserved on a slab split down the middle and are currently visible in coronal section (specimen PAS 338). At present they appear procoelous and could represent a large platynotan. They appear more elongate and slender than the isolated vertebra discussed above (PAS 337), but preparation is necessary to allow a more precise identification (Buchy *et al.*, in press).

Sixteen articulated partial procoelous vertebrae are preserved on a slab, visible in right lateral aspect (specimen PAS 336, Figure 5e). The neural arches are complete and fused to the centra. No transverse processes are visible, and the hemal arches are missing, having apparently been unfused to the centra. The cranialmost three neural arches increase in height terminally. The height of the nine following neural arches gently decreases terminally; the height of the terminalmost preserved neural arches is about 2/3 the height of the cranially preceding neural arch. These features allow the referral of the specimen to the third fourth of the tail of an early mosasaurid, about 3 m in length (Buchy *et al.*, in press). The slab does not show any trace of further vertebrae cranial to the cranialmost preserved vertebra. This indicates that the tail portion probably disarticulated prior to being embedded.

### Pterosaurs

The only known pterosaur specimen is an almost complete and articulated nyctosaurid pterosaur, which is under detailed study by Frey *et al.* (in press) and referred to a new genus and species, *Muzquizopteryx coahuilensis*. With a wingspan of about 2 m, it represents the smallest known adult nyctosaurid pterosaur. Due to the fact that the specimen comes from the earliest Coniacian (see below), it represents the earliest known nyctosaurid. The preservation of soft parts and the *in situ* preservation of the carpus allows the reconstruction of some distal arm muscles and a definite conclusion regarding the orientation of the pteroid bone.

### Invertebrates

The invertebrate assemblage consists of decapod crustaceans, ammonoids and bivalves (*e.g.*, inoceramids, oysters). Other benthic faunal elements (*e.g.*, sponges, brachiopods, gastropods, echinoderms) are apparently absent.

### Preservation of invertebrates

Ammonoids are preserved as compressed internal moulds (Figures 6a-d; 7a, b; 8a-f). Most are embedded laterally in the sediment, but occasional diagonally or vertically embedded specimens also occur and suggest the presence of soft or soupy sediment. Aptychi are mostly found isolated; in rare cases, they still rest in the living chamber. Our collection also includes specimens with a phosphatic preservation of the siphon (*e.g.*, Figure 6a, c), either complete or with different degrees of fragmentation.

Most inoceramids still preserve their thick prismatic shells, although the aragonitic layer is always recrystallized (Figure 9a-h). In a few specimens, the shell is replaced by goethite indicating very early diagenetic replacement of the periostracum by pyrite. Most inoceramid shells are closed, although separated valves, fragmented shells, or rarely shell hash also occur. Calcitic shells such as oysters, ammonoid aptychi, or foraminiferal tests, are preserved with minor recrystallization.

Phosphatization of the invertebrate fossils has been recognized in rare occasions, for instance in decapod crustacean carapaces or ammonite siphons.

### Ammonoids

Ammonoids regularly occur but are not common at El Rosario. Ten different species are identified: *Baculites yokoyamai* Tokunaga and Shimizu, 1926, *Gaudryceras mite* (von Hauer, 1866), *Forresteria (F.) alluaudi* (Boule *et al.*, 1906-07), *F. (F.) brancoi* (Solger, 1904) (Figure 6), *?Neocrioceras* sp., *Peroniceras tridorsatum* (Schlüter, 1867) (Figure 7), *Scaphites (S.) frontierensis* Cobban, 1952, *S. (S.) cf. S. (S.) preventricosus* Cobban, 1952, *S. (S.) sagensis* Cobban, 1952, and *S. (S.) uintensis* Cobban, 1952 (Figure 8). Baculitids are frequent and in places abundant in the



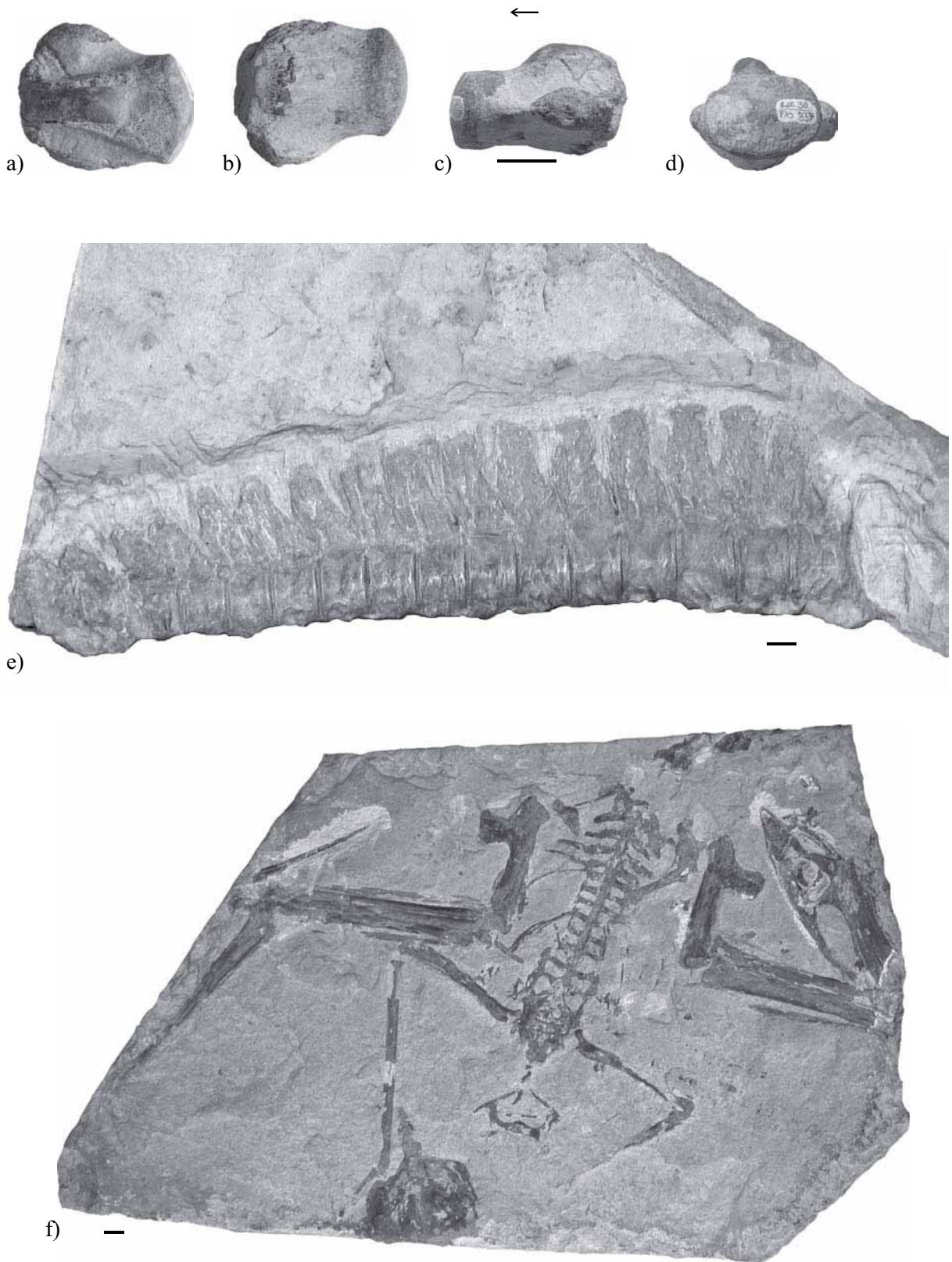


Figure 5. a-d: Undetermined squamate, partial caudal vertebra (PAS 337) from El Rosario, in (a) dorsal, (b) ventral), (c) right lateral and (d) caudal views. e: Undetermined mosasaur, PAS 336, from El Rosario, in right lateral view,  $\times 0.5$ . f: Nyctosaurid pterosaur (UNAM IGM 8621) *Muzquizopteryx coahuilensis* n.gen., n.sp., which is currently described by Frey *et al.* (in press). Scale bars 10 mm.

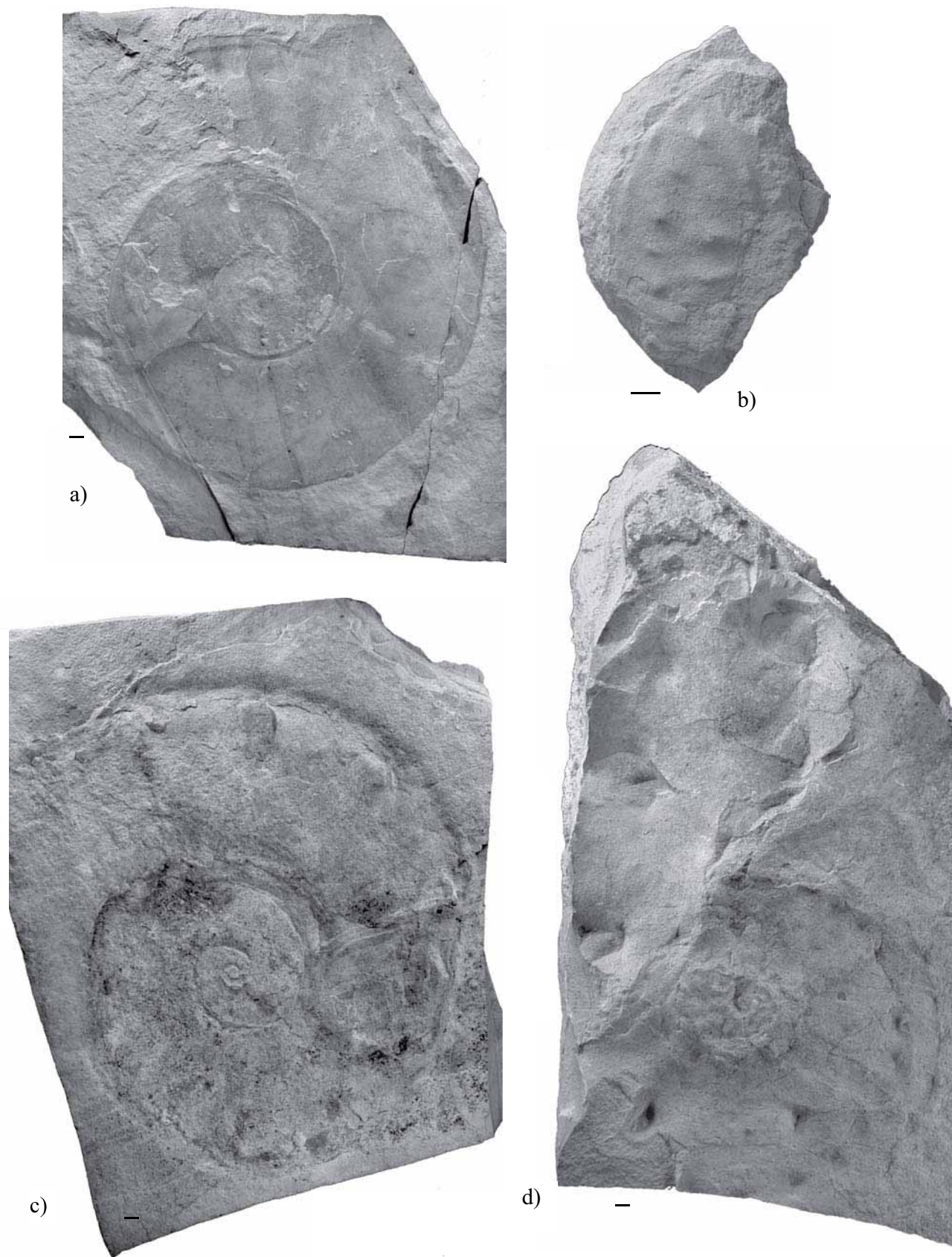


Figure 6. a: *Forresteria* (*Forresteria*) sp.  $\times 0.25$ . b: *F. (F.) alluaudi*,  $\times 0.5$ . c-d: *F. (F.) brancoi*,  $\times 0.25$ . Scale bar 10 mm.



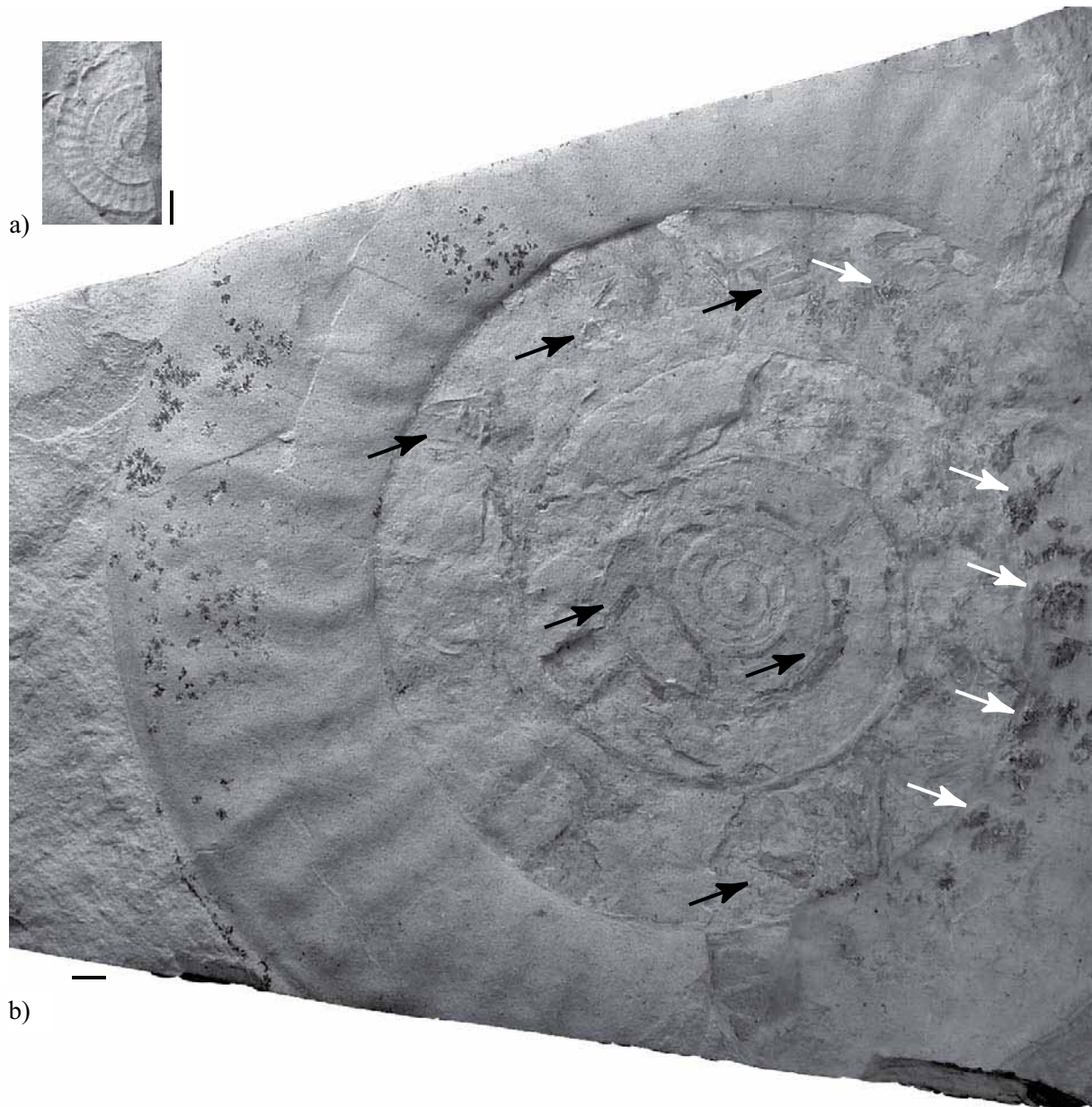


Figure 7. a-b: *Peroniceras tridorsatum*,  $\times 0.5$ . Scale bars 10 mm. White arrows: *Stramentum* sp. Black arrows: siphon preservation.

lower part of the yellow member, but are rare elsewhere. *?Neocrioceras* also occurs frequently, but is more evenly distributed throughout the section. Scaphitids are represented by species endemic to the Western Interior Seaway (see Cobban, 1952; Kennedy and Cobban, 1991). The distribution of the non-heteromorph ammonites is significantly more ample than that of the heteromorphs, and some species even occur worldwide in low and middle latitudes (see Kennedy and Cobban, 1991). Similar to other coeval strata in NE Mexico, no belemnites have been recorded, reflecting the general absence or rarity of belemnites in the Upper Cretaceous of this region.

### **Bivalves**

Inoceramids are abundant. Seven species were recognized. *Didymotis costatus* (Fric, 1893), *Mytiloides herbichi* (Atabekian, 1969), *M. incertus* (Jimbo, 1894), *M. scupini* (Heinz, 1930) are restricted to the gray member of the El Rosario sediment sequence. Higher in the section, these species disappear and several species of *Cremnoceramus* appear successively, with *C. waltersdorfensis waltersdorfensis* (Andert, 1911), *Cremnoceras deformis deformis* (Meek, 1871), *C. deformis erectus* (Meek, 1877) and *C. crassus inconstans* (Woods, 1912) identified so far (Figure 9a-h).

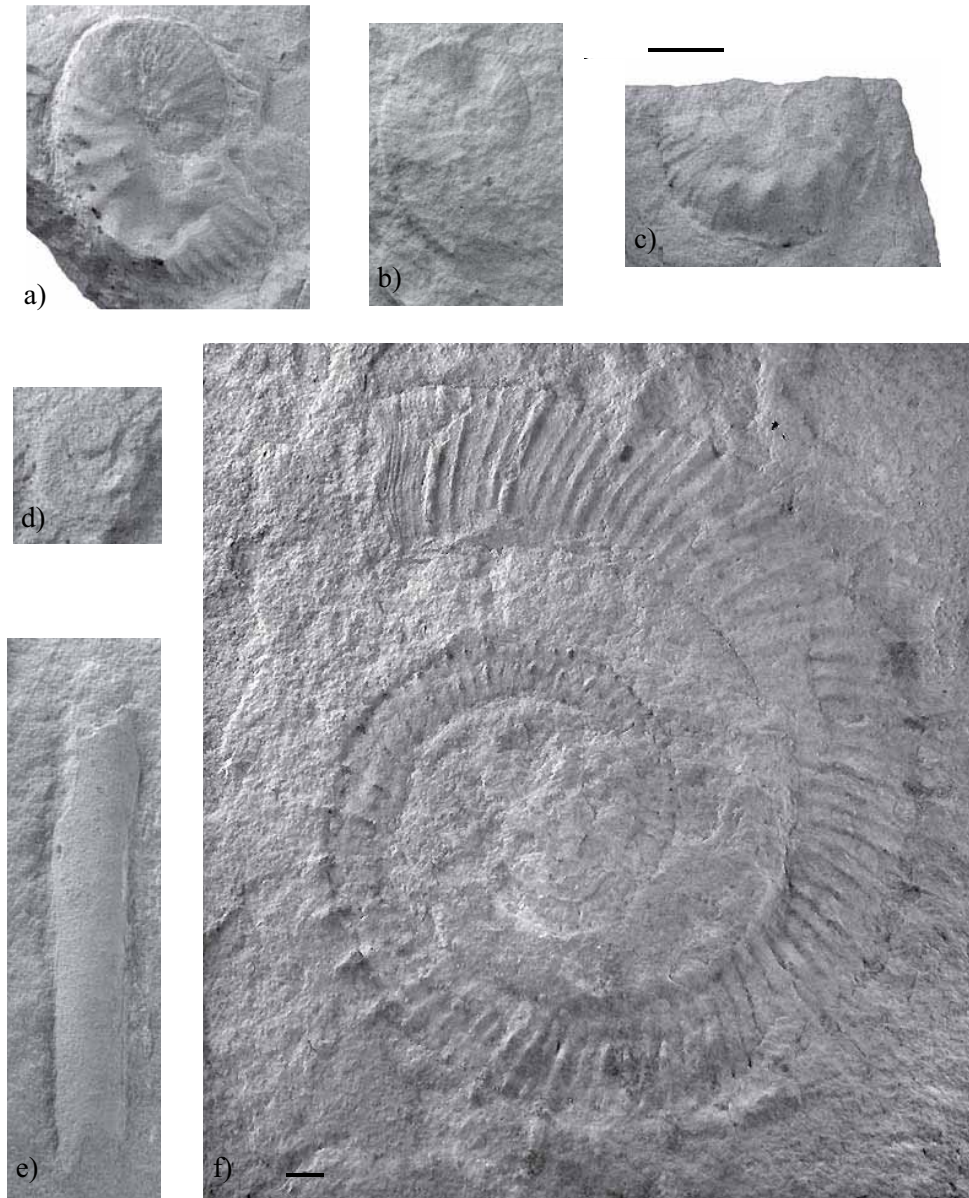


Figure 8. a: *Scaphites (Scaphites) uintens*. b: *S. (S.) frontierensis*. c: *S. (S.) sagensis*. d: *S. (S.) cf. S. (S.) preventricosus*  $\times 1$ . e: *Baculites yokoyamai*. f: *?Neocrioceras* sp.  $\times 0.5$ . Scale bars 10 mm.

Oysters are rare and have only been observed as epizoans, growing on a single plant fossil (Figure 9i).

### Crustaceans

Four species of crustaceans are present in the El Rosario carbonate sequence (Figure 9j-n). The most abundant form is a brachyuran, which resembles a species described by Feldmann *et al.* (1999) from the Turonian of Colombia as the carcineretid genus *Ophthalmoplax*, on the basis of flattened fifth pereiopods and spiny chelae, but without specific morphology of the carapace. The specimens from the Múzquiz *plattenkalk* are more complete and at least one specimen preserves dorsal carapace morphology, which

is different from any carcineretid described to date (Figure 9j). The morphology and size of flattened dactyl on the fifth pereiopod is different from those of typical carcineretids, such as *Carcineretes planetarius* from the Maastrichtian of Belize and Chiapas, Mexico, which has an oval, flattened dactyl (Vega *et al.*, 1997; Vega *et al.*, 2001). Our specimens from Coahuila show a small, unciform dactyl. Another feature present in both the Colombian and the El Rosario crabs is their long and flattened third maxillipeds, which seem to be relatively smaller in the Maastrichtian *C. planetarius* and in *O. difuntaensis* (Vega and Feldmann, 1991). A detailed description and discussion will propose a new family of brachyuran crustaceans for the Múzquiz specimens.



A second species is represented by two specimens, preserved well enough to distinguish this form from the previous one. Their carapax is elongate and pereopods have fine lateral spines (Figure 9n). The fifth pair of pereopods is also flattened, but the chelae seem to be much smaller than in other Múzquiz crabs.

Several pairs of long chelipeds, similar to *Callianassa* are also present in our collection (Figure 9k, 9l), but a preliminary observation suggests that this form may belong to the natantia group, instead of the reptantia.

A cirripedian, assigned to the genus *Stramentum* (Figure 9m) is represented by several specimens attached to a shell of the ammonite *Peroniceras tridorsatum* (Figure 7b). This cirripedian will be described in collaboration with Dr. Frank Wittler, Karlsruhe University, Germany.

Compared to fossil crustacean assemblages described from Upper Cretaceous sediments elsewhere (Maisey and Martins-Neto, 1991; Feldmann *et al.*, 1998; Vega *et al.*, 2003; Larghi, 2004), the Múzquiz crustaceans reveal a general morphological trend of structures, which facilitate swimming, such as the presence of spines on flattened legs and carapace. Another fact is that all brachyurans are represented by exuviae, which could be a reason why some are disarticulated. Only the cirripedian *Stramentum* is represented by corpses, which are attached to what appears to be their original habitat: a pelagic ammonite. Benthic elements in the Múzquiz crustacean assemblage have not been described until now. More data are needed to decide whether the Múzquiz crustacean assemblage is allochthonous and has been transported from a more proximal shelf environment, or whether it represents an autochthonous pelagic community.

### Microfossils

The El Rosario sediments contain rich and diverse planktic foraminiferal assemblages, which include abundant dicarinellids, hedbergellids, heterohelicids and globotruncanids (*e.g.*, *Dicarinella*, *Heterohelix*, *Marginotruncana*, *Whiteinella*; Figure 2f-i). This assemblage indicates open marine conditions and water depths of at least 50m.

Benthic foraminifers are extremely rare and confined to single specimens and a few horizons. Other than foraminifers, microfossil groups include abundant calcispheres and occasional ostracods which appear to be restricted to the upper member.

### Plant remains

Fossil evidence from vegetation of the North American continent to the north is scarce. A single leaf-like fossil, which could represent a thallophyte alga, with oyster overgrowth (Figure 9i) and occasional fragments of undetermined fossil wood have been discovered to date. The wood

cannot yet be assigned to any specific taxonomical group. According to the paleogeographic reconstructions for the Upper Cretaceous (*e.g.* Young, 1963; Corbett *et al.*, 1987; Kennedy and Cobban, 1991; Goldhammer and Johnson, 2001), the El Rosario sediments were deposited more than 100 km offshore. This implies that the wood drifted for a while, but was not drilled by teredinid or pholadid bivalves, nor is it covered by any epizoans. Probably, the wood remains represent the cores of rotten drift wood.

## BIOSTRATIGRAPHY

### The Turonian–Coniacian boundary

The candidate Global Standard Stratotype section and Point (GSSP) for the Turonian–Coniacian boundary is the Salzgitter–Salder section in Germany, where the boundary interval is marked by a radical change from the late Turonian *Mytiloides*–*Inoceramus*-dominated inoceramid fauna to the *Cremnoceramus*-dominated fauna of the latest Turonian and early Coniacian. This change allows a detailed zonation of late Turonian and early Coniacian sediments. The first appearance (FAD) of *Cremnoceramus deformis erectus* (for which *C. rotundatus* is a synonym) defines the base of the Coniacian (Walaszczyk and Wood, 1998; Gradstein *et al.*, 2004). These zones are well correlated to the ammonite zonation of the Western Interior Sea (Walaszczyk and Cobban, 2000). Figure 10 gives an overview on late Turonian and Coniacian ammonite and inoceramid ranges known from the Western Interior Seaway and the zonation based on it. Most species known from this region also occur in the El Rosario limestone sequence.

Prior to Walaszczyk and Wood (1998), the boundary was based on the FAD of the ammonite *Forresteria* (Kauffman *et al.*, 1996), but the FAD of this genus turned out to be diachronous (see discussion in Walaszczyk and Cobban, 2000, p. 4f).

### Position of the Turonian–Coniacian boundary at El Rosario

Based on ammonites, the Austin Group was considered to be of Coniacian–Santonian age (Sohl *et al.*, 1991). Later, Goldhammer and Johnson (2001) reported a late Turonian–Santonian age for the same unit. Our preliminary analysis of the El Rosario sequence indicates that the Turonian–Coniacian boundary is present and biostratigraphically complete, including most ammonite, scaphitid, inoceramid and planktic foraminiferal marker species. The section may thus be suitable to define a hypostratotype of the Turonian–Coniacian boundary in the transitional zone between the Western Interior Seaway and the western Tethys.

The presence of the *Mytiloides scupini* assemblage in the gray member indicates a late Turonian age for the

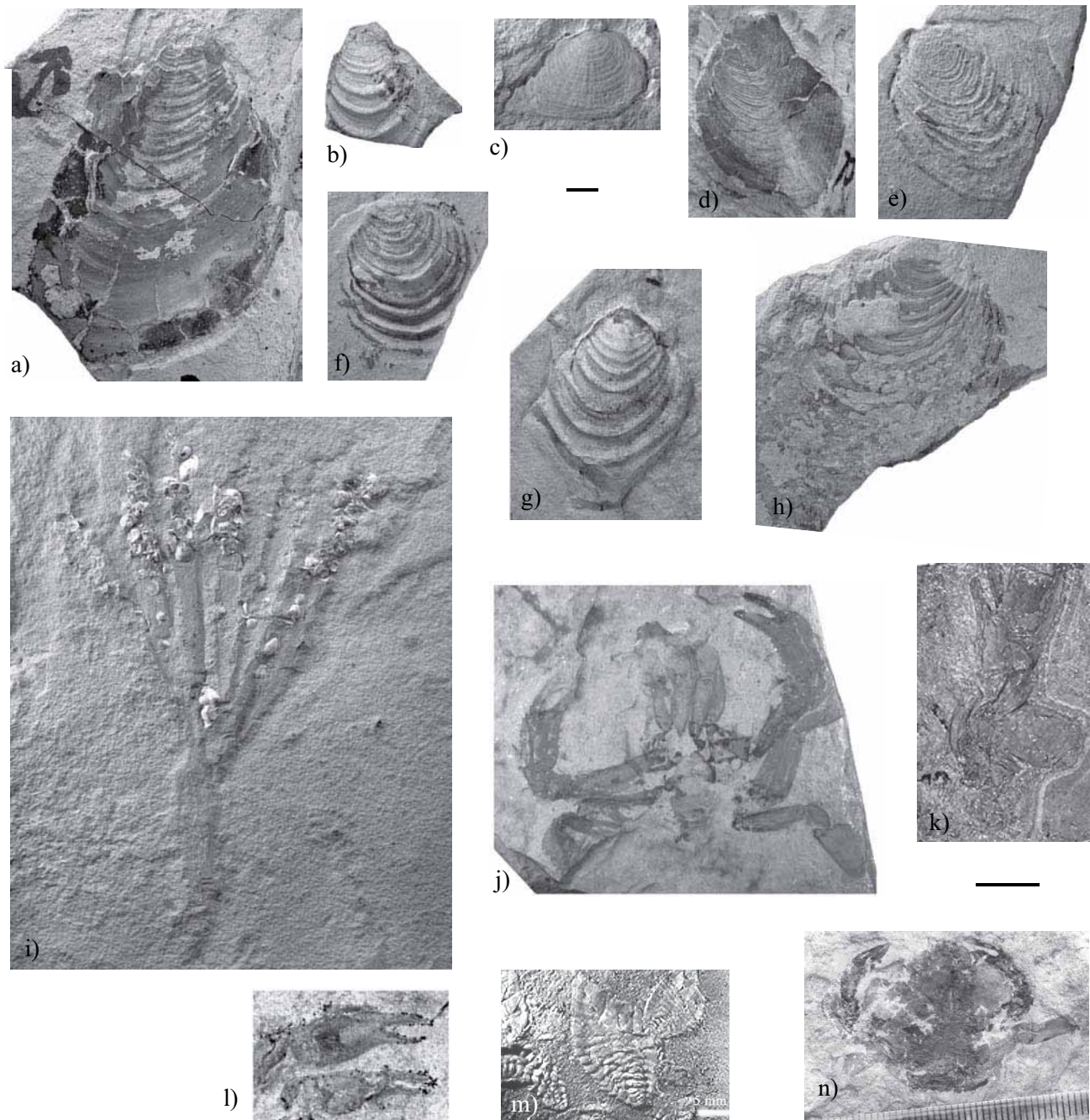


Figure 9. a: *Mytiloides scupini*. b: *M. incertus*. c: *Didymotis costatus*. d: *Mytiloides herbichi*. e: *Cremonoceramus waltersdorfensis waltersdorfensis*. f: *C. deformis erectus*. g: *C. deformis deformis*. h: *C. crassus inconstans*. i: Ostreids on a possible thallopiphyte alga,  $\times 0.5$ . j: New brachyuran species, ventral view. Note third maxillipeds and chelae. k-l: Callianassid? chelae. Carapace is partially preserved. m: *Stramentum* sp. Several specimens attached to shell of the ammonite *Peroniceras tridoratum*. n: New brachyuran species, dorsal view,  $\times 1$ . Scale bars 10 mm.

lower part of the El Rosario section (Figure 3). Upsection, *M. scupini* and related species disappear and are replaced by the *Cremonoceramus* assemblage. The first appearance of *Cremonoceramus deformis erectus* marks the base of the Coniacian in the lower part of the yellow member at 25.0 m in the section (sample 40). *Cremonoceramus crassus inconstans* has only been found in the white member of the

Rosario section. The FAD of this species permits further subdivision of the early Coniacian. The absence of the early Coniacian zonal markers *C. waltersdorfensis waltersdorfensis*, *Cremonoceramus deformis dobrogenensis* and *C. crassus crassus* may be due to sampling bias. More detailed stratified sampling is necessary to prove the presence or absence of these zones.

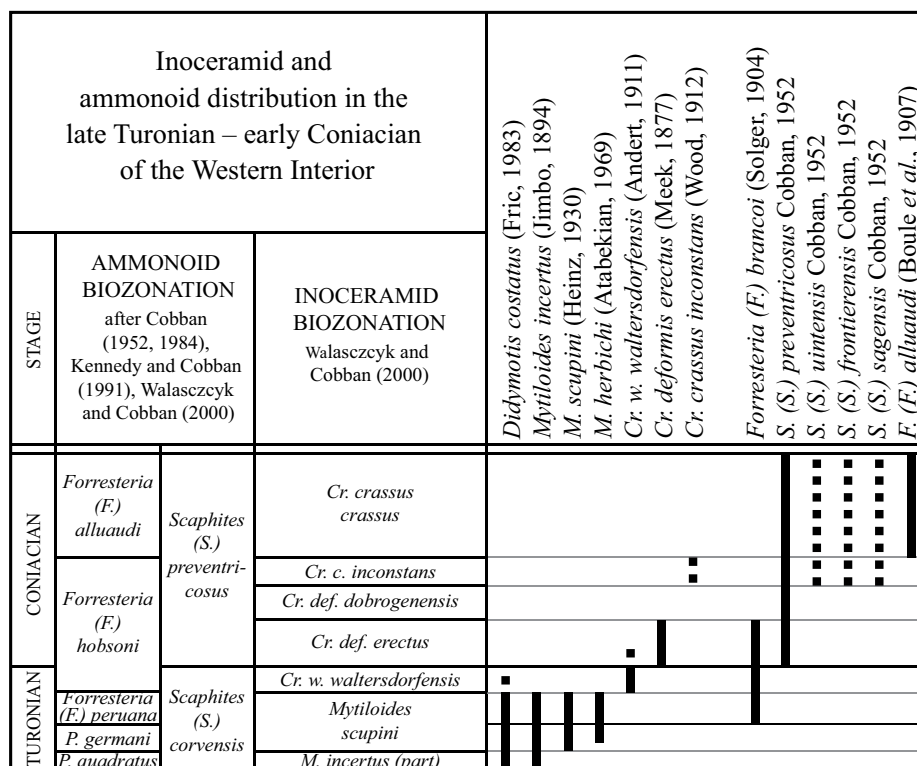


Figure 10. Stratigraphic ranges of inoceramids and ammonoids and biozonation for the late Turonian–Coniacian of the Western Interior (after Walaszczyk and Cobban, 2000; Seeling and Bengtson, 2003).

Isolated specimens of *Peroniceras tridorsatum* and *F. (Forresteria) brancoi* are present at 19 m and 25.5 m in the section. These ammonites were used in the past to define a Coniacian age for the base of the Austin Group (e.g., Sohl *et al.*, 1991). But *F. (Forresteria) brancoi* is now considered to be of latest Turonian and early Coniacian age and spans from the upper *M. scupini* to the upper *C. deformis erectus* zone (Walaszczyk and Cobban, 2000, see Figure 10).

The planktic foraminiferal associations confirm the position of the Turonian–Coniacian boundary at El Rosario (Figure 3). After Premoli-Silva and Sliter (1999), *Dicarinella primitiva* and *Marginotruncana sigali* characterize a late Turonian foraminiferal zone. *M. sigali* is present throughout the El Rosario sediment sequence, whereas *D. primitiva* was not recorded prior to the 25.0 m level (sample 40). The index fossil of the lower Coniacian *Dicarinella concavata*-Zone first appears at 25.5 m (sample 42), at the top of the bank containing the basal Coniacian inoceramid index fossil *Cremnoceramus deformis erectus* (Figure 3).

**PALEOGEOGRAPHY**

During Turonian–Coniacian times, the North American coastline was located at least 200–300 km to the west of El Rosario (e.g., Young, 1963; Corbett *et al.*, 1987; Kennedy and Cobban, 1991; Goldhammer and Johnson, 2001, and

Figure 11). Likely, the latitudinal position was similar to that of recent times, which suggests a subtropical climatic setting and periodic variations in seasonal temperature.

**SEDIMENTARY ENVIRONMENT**

Primary millimetric lamination is ubiquitous in both limestone and marls of the El Rosario section. Lamination, fine grained texture, predominance of randomly oriented fossils, and the fossil assemblage itself indicate sedimentation in a quiet water marine environment. Stagnation and a hostile oxygen-deficient bottom environment are indicated by the near-absence of trace fossil and benthic invertebrate associations, except for inoceramids, as well as the millimetric lamination of the sediment. Anoxic conditions are also indicated by thin laminae to thick horizons with concretions of goethite, which formed from the oxidation of primary pyrite, and by the early diagenetic phosphatization of vertebrate and invertebrate fossils. A combination of these factors is commonly associated with localities showing exceptional fossil preservation (*i.e.*, *Konservat-Lagerstätten* of Seilacher, 1990). The presence of inoceramids does not necessarily indicate an oxic environment on the sea floor. On the contrary, these bivalves apparently flourished under oxygen-deficient conditions in the oxygen minimum zone. They may have sheltered chemoautotrophic microbes as

symbionts, taking direct advantage of a redox gradient in the benthic boundary layer (e.g., MacLeod and Hoppe, 1992; Fischer and Bottjer, 1995).

Low energy currents occurred only occasionally and probably very locally. They are indicated by subparallel-oriented shafts of *Baculites*, transported along with small inoceramids or inoceramid shell debris. These coquina layers are very rare and restricted to patches with no lateral extension. Depositional structures, such as cross bedding, ripples, or roll marks of ammonoids are absent. This scarcity of sedimentary structures, attributable to traction transport, suggests deposition below storm wave base. After having sunk to the sea floor, vertebrate carcasses and invertebrate shells were not transported far or moved by waves or currents. This preliminary set of data on the El Rosario carbonate sequence coincides with a classical stagnation deposit.

The abundance of ammonoids, inoceramids and planktic foraminifera, especially globotruncanids, as well as the rare plant remains indicate a water depth of at least 50 m, an open marine shelf environment and normal stenohaline conditions. The extremely rare shallow water, terrestrial and semi-aquatic organisms, and drift wood suggest a distant coast line (>100 km), an interpretation which agrees well

with the general paleogeographic reconstructions for the region (e.g., Young, 1963; Corbett et al., 1987; Kennedy and Cobban, 1991; Goldhammer and Johnson, 2001). Lithologies at El Rosario may be similar to Solnhofen, but the two deposits reflect markedly different environments. The Solnhofen model of a lagoonal basin or closed embayment in a near shore environment (Barthel et al., 1990) is not applicable to the El Rosario sequence, which was deposited in an open marine shelf environment. These characteristics also preclude direct comparison to lagoonal *plattenkalk* deposits such as the Crato Formation in NE Brazil (Martill, 1993b), and possibly the Tlayúa Formation in the Mexican state of Puebla (see discussions on Tlayúa in Pantoja-Alor, 1990 (1992); Espinosa-Arrubarena and Applegate, 1996; Kashiwama et al., 2004).

CONCLUSIONS

Our preliminary set of data on the El Rosario carbonate sequence suggests that the sediments represent a classical stagnation deposit with an enigmatic vertebrate assemblage, which is indicated by the hitherto unknown

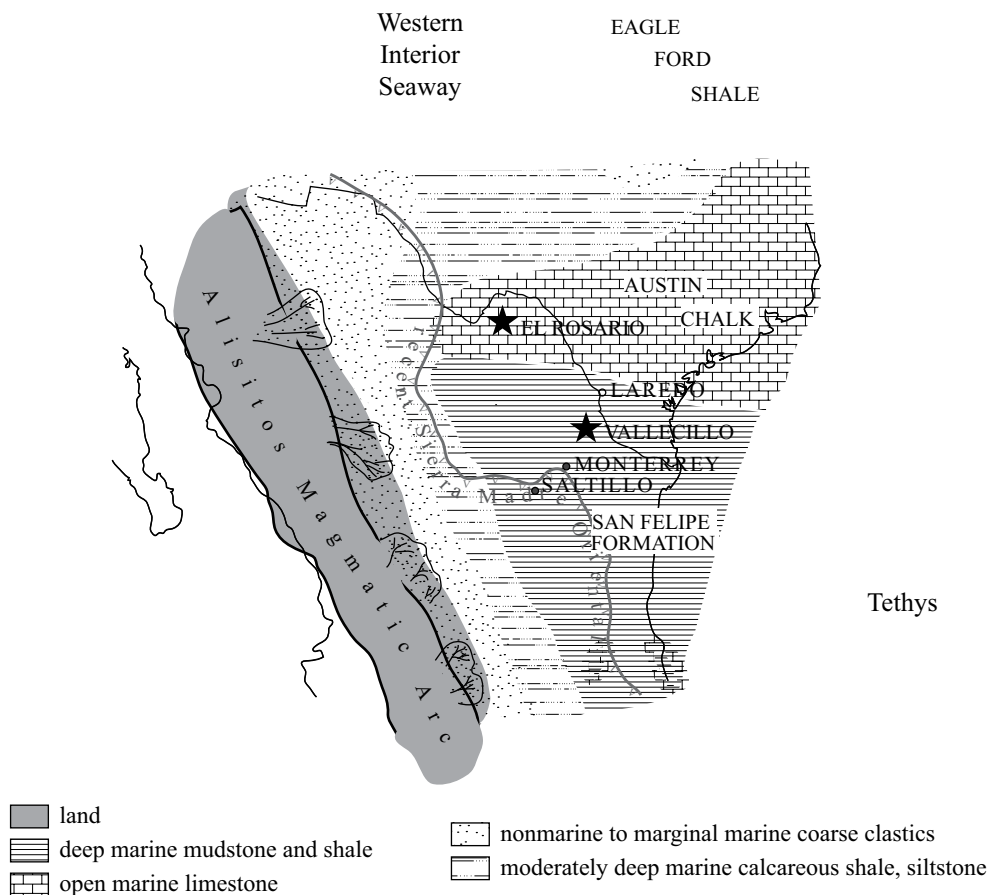


Figure 11. Paleogeography of the northwestern Gulf of Mexico basin during the Coniacian, with location of the El Rosario and Vallecillo *plattenkalk* localities in NE Mexico (modified from Young, 1963; Corbett et al., 1987; Kennedy and Cobban, 1991; Goldhammer and Johnson, 2001 ).



early mosasaurids, the possible crocodylian and the nyctosaurid pterosaur. The excellent preservation, even of soft parts, appears to be the result of oxygen-deficient bottom conditions, early diagenetic phosphatization, and a rapid burial in a soft, micritic lime mud. The age of the sediments is late Turonian–early Coniacian. Deposition occurred in an open marine shelf environment, at least 100 km away from the coast line, and in water depths of at least 50–100 m.

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