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Confrontation of stratigraphic methods to define the Jurassic-Cretaceous boundary in eastern Mexico subsurface

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ABSTRACT

This study determined the Jurassic-Cretaceous boundary over a 1300 km, three-part subsurface section by comparing ammonites, calpionellid microfossils, and radioactive logs from oil wells in east and northeast Mexico. Cores from 26 wells ranging in depth between 400 m and 3000 m established that the top of the Tithonian was defined by ammonites *Durangites* and *Proniceras*, and the Berriasian was determined by *Berriasella* aff. *jacobi* and *Subthurmannia*. Both pairs allowed regional characterization of the Jurassic-Cretaceous boundary in the coastal plain of the Gulf of Mexico. These ammonites establish stratigraphic correlations with southern Europe, the Middle East, Cuba, Argentina, and California. *Calpionella alpina* and *C. elliptica* appear simultaneously from the upper Tithonian to the Berriasian, making them unreliable fossils for determining this boundary.

PREVIOUS STUDIES

Eastern Mexico provides abundant surface and subsurface data with which to establish the Jurassic-Cretaceous boundary. Researchers have historically determined this limit by ammonites (Burckhardt, 1930; Cantú-Chapa, 1967, 1976; Imlay, 1980); some microfossils have contributed to a lesser degree (Bonet, 1956; Trejo, 1960). Subsurface samples containing ammonites and microfossils taken from oil wells were correlated to corresponding wirelogs to determine the precise depths and stratigraphic distribution within the sedimentary sequences near the boundary (Cantú-Chapa, 1982).

In southeastern France researchers established this boundary using berriasellid ammonites and calpionellid microfossils. Although researchers have suggested this area as the stratotype for the boundary, they have not yet established it (Le Hegarat, 1971; Le Hegarat and Remane, 1968; Mazenot, 1939). Further studies of these fossils have generated theoretical biostratigraphic subdivisions that let researchers characterize the Jurassic-Cretaceous boundary in this Mediterranean area (Geyssant, 1997; Hoedemaeker, 1990, 1991). Likewise, researchers have also studied this boundary by means of ammonites in Iraq, Cuba, and Argentina (Howarth, 1992; Leanza, 1945; Myczynski, 1989, 1994; Myczynski and Pszczólkowski, 1994; Westermann, 1993).

STRATIGRAPHIC METHODS USED TO DEFINE THE JURASSIC-CRETACEOUS BOUNDARY IN MEXICO

The definition of the Jurassic-Cretaceous boundary represents a classic chronostratigraphic study. In Mexico, several authors relied on biostratigraphic methods to determine the boundary using only the presence of ammonites in outcrops and subsurface sedimentary sequences (Cantú-Chapa, 1967, 1976, 1982; Verma and Westerman, 1973). Of all the tools used to define the Jurassic-Cretaceous boundary in Mexico, only these fossils have proven reliable. As their representatives belong to different families, a larger number of supporting biostratigraphic elements complement each other. For example, *Kossmatia*, *Proniceras*, and *Durangites* do not transgress the top of the Jurassic and *Subthurmannia* and *Spiticeras* characterize only the base of the Cretaceous (Berriasian).

Studies in Mexico and other regions of the world such as Cuba, Iran, and north Africa (Pszczólkowski, 1987; Edgell, 1971; Colom et al., 1954) have shown that no other microfossils (*Cal-*

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pionella alpina and *C. elliptica)* can define the top of the Jurassic or the base of the Cretaceous, because they do not characterize either of the periods (cf. Remane, 1963; Allemann et al., 1971; Van Hinte, 1976).

This study confirms observations in Mazatepec, eastern Mexico, concerning the unsuitability of these two species of calpionellids to define this stratigraphic boundary; both species appear from the top of the Upper Jurassic to the base of the Lower Cretaceous (Cantú-Chapa, 1967). Federico Bonet (now deceased) performed these unpublished micropaleontologic determinations in the Petroleos Mexicanos Micropaleontology Laboratory (now closed). This chapter is based in part on Bonet's invaluable determinations, integrated with radioactive logs and ammonites to build stratigraphic sections.

WIRELOGS TO ESTABLISH THE PIMIENTA–LOWER TAMAULIPAS FORMATIONS CONTACT (JURASSIC-CRETACEOUS) IN OIL WELLS IN EASTERN MEXICO

If researchers defined the Jurassic-Cretaceous boundary using wirelogs alone, they could only establish lithostratigraphic subdivisions of no chronostratigraphic value that would fail to identify lateral facies changes. Lithostratigraphic divisions based on electric logs often do not show any noteworthy changes in the Mesozoic sedimentary sequences, nor do they help to establish correct lithostratigraphic subdivisions.

The flat spontaneous potential (SP) curve does not allow precise definition of the contact between the Upper Jurassic Pimienta and the Lower Cretaceous Lower Tamaulipas Formations. Therefore, a stratigraphic correlation with neighboring wells based on this log alone would be subjective. In contrast, the gamma ray curve does show abrupt changes through the same sedimentary sequences. Figure 1 compares these two log types from the Camaitlan 2-well in eastern Mexico, originally studied separately for stratigraphic and petroleum content objectives (Lopez, *in* Cantú-Chapa 1992). The two logs produce distinct graphic expressions. The radioactive log clearly depicts the abrupt change of argillaceous limestones of the Pimienta Formation to the micritic limestones of the Lower Tamaulipas Formation. Researchers cannot infer the Jurassic-Cretaceous boundary from these two formations. They should also consider the different depths for establishing contacts when comparing the electric and radioactive logs. These vary considerably depending on the log type used, and are apparent in the well analyzed here (Fig. 1).

JURASSIC-CRETACEOUS BOUNDARY AND ZONATION BY MEANS OF CALPIONELLIDS

Researchers consider certain calpionellid species as the proper fossils to define the Jurassic-Cretaceous boundary. To characterize the stages closer to the boundary, Remane's (1963) studies in southeastern France proposed three zones based on these microfossils; researchers have compared these zones to

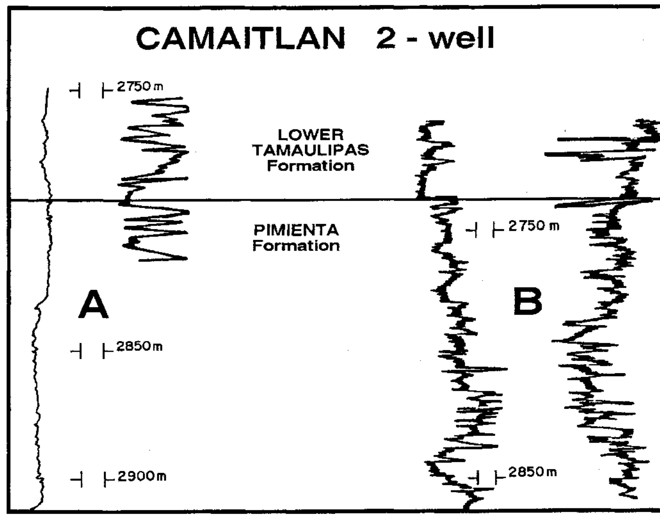

Figure 1. Characterization and location of contact between Pimienta and Lower Tamaulipas Formations (Jurassic and Cretaceous, respectively) vary depending on spontaneous potential (SP) curve and radioactive logs used. Camaitlan 2-well, eastern Mexico . (A) After López (1985, cited *in* Cantú-Chapa, 1992). B: After Cantú-Chapa (1992).

ammonite species of the genus *Berriasella* (Le Hégarat, 1971). Zone A, containing *Crassicollaria,* represents the base of the Upper Jurassic biostratigraphic succession containing such fossils; zone B, containing *Calpionella,* overlies it, and is in turn overlain by zone C, which contains *Calpionellopsis.* Zone B was originally set astride the Jurassic-Cretaceous boundary. The limits of zone C do not coincide with the boundaries of the stages as classically defined by ammonites (Table 1).

Remane (1963) subjectively established the boundaries and characterized the zones based on calpionellid population percentage (Le Hégarat and Remane, 1968). This is not a rigorous biostratigraphic methodology that could resolve the major chronostratigraphic issue of the Jurassic-Cretaceous boundary in that region of southern of France and by extension of the whole region of the Tethys sea. Remane (1997) endeavored to apply his zonation approach with calpionellids in Mexico, having published 10 papers on the subject (Adatte et al., 1991, 1992, 1994a, 1994b, 1994c, 1996a, 1996b; Stinnesbeck et al., 1993, 1997).

To define a paleontologic zone, one must take into account such significant evolutionary events as the abrupt appearance, disappearance, or acquisition of a morphologic feature in one or several isochron organisms within a sedimentary sequence. Failing this, chronostratigraphic problems arise when characterizing a boundary of such magnitude. Such problems arose when researchers used calpionellids for zonation, generating a series of contradictions that in turn have affected zonation by ammonites. Some ammonite specialists have succumbed to these biostratigraphic vicissitudes of micropaleontology, due either to a lack of awareness or to inadequate methodological analysis (Le Hégarat, 1971; Oloriz and Tavera, 1989; Jeletzky, 1984; Zeiss, 1986).

Remane (1963, p. 63) recognized this micropaleontologic error: ". . . the Jurassic-Cretaceous boundary cannot be characterized with calpionellids because there are no breaks in the development of those fossils at that level. . . ." To amend his proposal, Remane divided zone B into two subzones, integrating zone C as a subzone of zone B, while still setting them astride the boundary between the Tithonian and the Berriasian (Le Hégarat and Remane, 1968) (Table 1). Remane displaced zone B with *Calpionella* to the Berriasian; he applied this approach in a stratigraphic study on the Jurassic-Cretaceous boundary carried out in Mexico. A recommendation from the International Symposium on the Jurassic-Cretaceous boundary held in Lyon-Neuchatel in 1973 justified that displacement (Adatte et al., 1994a, 1994b; Stinnesbeck et al., 1993). This was a theoretical proposal, and stratigraphic studies have not verified it. To date, problems have arisen in applying it to establish the boundary (Cantú-Chapa, 1996).

At the same symposium, Remane suggested that researchers lower the boundary's position to the base of the *jacobi-grandis* ammonite zone to match it with the base of the *Calpionella* zone (Adatte et al., 1994a, 1994b, 1994c; Stinnesbeck et al., 1993). However, this proposal generates a contradiction, because one of those papers locates the classic Jurassic-Cretaceous boundary in the middle of zone B with *Calpionella* (Adatte et al., 1994, 1944a).

A Jurassic-Cretaceous boundary study in Mexico concluded that neither ammonites nor calpionellids could define this boundary (Adatte et al., 1991, 1992, 1994a, 1994b, 1994c, 1996a, 1996b; Remane, 1997; Stinnesbeck et al., 1993, 1997); this conclusion seems in error because ammonites already define said limit. Remane (1997) proposed different ways to establish the Jurassic-Cretaceous boundary for the Tethyan region based on calpionellids, and extended his proposal to Mexico. Nonetheless, Remane (1997) acknowledged serious doubts when establishing this boundary in the Tethyan region, including difficulties in defining the boundary within zone A with *Crassicollaria* (Jurassic) and zone B with *Calpionella* (Cretaceous). He also observed that the *Crassicollaria* extinction is not a definite feature determining the boundary. As an alternative, he proposed using a morphologic change of *Calpionella alpina*, though he considered it impossible to separate the two forms of that species in formal taxonomic terms. He concluded that establishing three boundaries within zone B with *Calpionella* only allows for an approximate determination of the base of the Berriasian.

Table 1 shows how the proposed calpionellid- and *Berriasella*-ammonite–based stratigraphic relationships evolved in defining the Jurassic-Cretaceous boundary in southeastern France. Theoretically, this not-well-defined location has been considered as the stratotype for this boundary.

AMMONITES OF THE JURASSIC-CRETACEOUS BOUNDARY IN SOUTHERN EUROPE

Researchers have tacitly considered southern France the classic location to establish the Jurassic-Cretaceous boundary on the basis of studies of ammonites (Mazenot, 1939; Le Hégarat, 1971). However, they have not been able to establish the strato-

TABLE 1. EVOLUTION OF STRATIGRAPHIC RELATIONSHIPS BETWEEN CALPIONELLIDS AND THE BERRIASELLA AMMONITE SPECIES (*JACOBI AND GRANDIS*) IN THE MEDITERRANEAN REGION

	Le Hegarat (1971)		Hoedemaeker, et al. (1993) and Geyssant (1997) Zone:	Subzone:	Remane (1997)
					Zone E Calpionellites
Valanginian		Zone D Calpionellopsis	Otopeta		
	Boissieri		Boissieri		Zone D Calpionellopsis
Berriasian	Occitanica	Zone C Tintinnopsella	Occitanica		
				Grandis	Zone B (+C)
	Grandis		Jacobi	Jacobi	Calpionella
	Jacobi	Zone B Calpionella	Durangites		Zone A Crassicollaria
Upper Tithonian			Microcanthum		
	Transitorius	Zone A Crassicollaria			

type that characterizes the boundary. Traditionally, researchers have defined it using *Berriasella*-genus species, even though they do not show enough morphologic mutations to support chronostratigraphic elements. Two *Berriasella* species, *B. jacobi* and *grandis*, characterize two zones at the Jurassic-Cretaceous boundary in southern France and elsewhere in the Mediterranean region (Hoedemaeker, 1987; Oloriz and Tavera, 1989; Tavera, 1985). However, the morphologic differences do not correspond to the open stratigraphic problem; this casts doubts on their use for this purpose. Researchers have displaced these zones from the Tithonian's top to the base of the Cretaceous (Geyssant, 1997; Hoedemaeker, 1987, 1991; Tavera, 1985) (Table 2).

The various displacements throughout different ages of the *Berriasella* species found in the Jurassic-Cretaceous boundary have occurred because researchers have based the zones on calpionellids alone and not on the morphologic characteristics of these ammonites, which researchers have not analyzed for their biostratigraphic utility. Le Hégarat (1971, p. 298) failed to establish the boundary between these two systems either with ammonites or calpionellids: "... the transition from the Tithonian to the Berriasian is not paleontologically characterized since there are no fundamental changes at that level... ", and also wondered "... if said boundary could be displaced to make it correspond to a more significant change of fauna...."

Researchers agreed to put the Jurassic-Cretaceous boundary at the top of the zone containing *Durangites* in southern Spain (Enay and Geyssant, 1975), extending it to southeast France (Geyssant, 1997). The difficulty of establishing a stratotype for the southeastern French boundary persists. *Durangites* is an ammonite species from the upper Tithonian originally described in Mexico in San Pedro del Gallo (Burckhardt, 1912).

International congresses have voted to place the boundary within that region of France without specifying a stratotype that can corroborate the boundary (Hoedemaeker, 1991). Researchers can only resolve the Jurassic-Cretaceous boundary problem using representatives from other ammonite families with more restricted biogeographical spectra and significant morphologic mutations, and not with the *Berriasella* genus alone, as they have attempted in southern Europe.

The simultaneous appearance of the *Durangites* and *Proniceras* genera in southern Europe constitutes an interesting biostratigraphic element for establishing this boundary. These fossils have morphological features that strongly characterize the last bed of the upper Tithonian; therefore, they represent a key element in defining the upper limit of the Jurassic and correlating it regionally with the Middle East and the American continent, where they are also present. Field researchers have found *Durangites* and *Parodontoceras* in both Iraq and Mexico, allowing stratigraphic correlation among the upper Tithonian sequences (Cantú-Chapa, 1967, 1976; Howarth, 1992; Spath, 1950; Verma and Westerman, 1973). However, researchers have not considered the first genus for chronostratigraphic purposes in the Mediterranean region.

Of all the biostratigraphic proposals, the most coherent in characterizing the Jurassic-Cretaceous boundary are those based on specific genera features or events, such as the sudden disappearance of the *Durangites* and *Proniceras* genera from the top layers of the Tithonian, allowing correlation with other regions of the world wherever these fossils are present.

JURASSIC-CRETACEOUS BOUNDARY IN THE NORTHEASTERN MEXICO SUBSURFACE

This chapter studies a 400-km-long section in northeast Mexico using oil-well samples (Fig. 2). The section's northern part has a transitional contact between the La Casita and the Taraises Formations, and to the south, between the La Casita and Lower Tamaulipas formations, the contact is abrupt, as shown by the gamma ray curve of the logs. These formations are located at the Jurassic-Cretaceous boundary, as shown by paleontological material from both the surface and the subsurface.

The Taraises Formation consists of argillaceous limestones

TABLE 2. TWO PROPOSALS TO SUBDIVIDE THE JURASSIC–CRETACEOUS BOUNDARY IN SOUTHEASTERN FRANCE USING SPECIES OF THE BERRIASELLA GENUS (JACOBI AND GRANDIS), AND COMPARISON WITH DURANGITES AND PRONICERAS FOUND IN MEXICO

	Hoedemaeker (1987, 1991) SE of Europe		Geyssant (1997) SE of Europe		Important Ammonite Genera from Mexico (This chapter)
	Rarefurcata		Boissieri		
Berriasian			Occitanica		Subthurmannia
	Occitanica		Jacobi	(Grandis-jacobi)	Berriasella aff. jacobi
		Grandis	Durangites		Durangites–
	Euxinus				Proniceras
Upper		Jacobi			
Tithonian			Microcanthum		
	Durangites				

TABLE 3. BIOSTRATIGRAPHIC SUCCESSION OF AMMONITES AND CALPIONELLIDS IN NORTHEASTERN MIXICO

Stage (Formation)	Ammonites Outcrops:	Subsurface:	Characteristic Calpionellids	Others:
Berriasian (Taraises Fm./ Lower Tamaulipas Fm.)	Spiticeras			
Upper Tithonian (La Casita Fm.)	Proniceras–Durangites–Salinites	Proniceras–Kossmatia–Substeueroceras 20 m Salinites	Elliptica–Alpina	Carpathica–oblonga
	Suarites	Acevedites–Haploceras 25 m		

appear in the last 20 m before the upper contact of the La Casita Formation and up to 80 m into the calcareous body of the overlying Taraises Formation. Therefore, these two microfossils are not characteristic of either period. Table 3 was prepared with these biostratigraphic data.

JURASSIC-CRETACEOUS BOUNDARY OF EASTERN MEXICO SUBSURFACE

The Bejuco 6-well in the eastern Tampico region provided an excellent succession of ammonites that characterize the Jurassic-Cretaceous boundary. Simultaneous use of radioactive logs helped locate the cores taken from the boundary and to establish regional correlations (Cantú-Chapa, 1976).

The upper Tithonian is represented by only 20 m of continuous core (1961–1941 m, rotary table). Lithostratigraphically, it corresponds to the top of the Pimienta Formation, which consists of a regular alternation of bentonite layers and argillaceous limestones. The gamma ray curve shows a remarkable behavior that highlights the lithologic characteristics of the Pimienta Formation; it generally runs to the right of the track, showing several strong inflections (Fig. 3).

Cores 7, 8, and 9 from the Bejuco 6-well contain abundant ammonites that characterize the upper Tithonian. The Jurassic-Cretaceous boundary is very well defined at 1941 m (rotary table). Above this depth, the Berriasian ammonites *Subthurmannia* sp., *Neolissoceras semisulcata* Cantú, and *Berriasella* (*Berriasella*) aff. *jacobi* Mazenot occur. Below this depth the ammonite assemblage includes the following upper Tithonian taxa: *Salinites grossicostatum* (Imlay); *Proniceras victoris* Burckhardt; *Proniceras subpronum* Burckhardt; *P. subtorrense* Cantú; *P.* aff. *victoris* Burckhardt; *P.* aff. *subpronum* Burckhardt; *Durangites* aff. *vulgaris* Burckhardt; *Corongoceras* aff. *mendozanum* (Behrendsen) *in* Verma and Westermann; *Haploceras veracruzanum* Cantú; cf. *Glochiceras ecarinatum* (Imlay); *Durangites* sp.; *Salinites inflatum* (Imlay); *Salinites* sp. juv.; and *Salinites* sp.

The Jurassic-Cretaceous boundary marks a clear and well-defined lithological difference in the Bejuco 6-well. Above the aforementioned depth, there are very clear cream-colored porcelaneous micritic limestones with small concretions of white chert that correspond to the Lower Tamaulipas Formation. This lithologic character is well observed in the gamma ray curve above 1941 m, where it shifts abruptly to the left, remaining in that position as it logs the limestones that characterize that formation. Below that depth, the curve displaces to the right, corresponding to the Pimienta Formation's argillaceous limestone. Core 7 (1937–1943 m) was cut right at the Jurassic-Cretaceous boundary. The lower part corresponds to the Pimienta Formation and the upper to the Lower Tamaulipas Formation. The Berriasian rocks are 12 m thick; their upper boundary is located at 1928 m (rotary table). This latter formation is where the ammonite *Berriasella* (*Berriasella*) aff. *jacobi* Mazenot, originally attributed to the *B. neohispanica* Burckhardt, was found (Cantú-Chapa, 1976, plate III, Fig. 13). This study determined that it is very similar to the species found in southern France (Mazenot, 1939). This makes it a very important biostratigraphic element for correlating the Berriasian rocks of this region (Fig. 3).

Calpionellids were not studied in the Bejuco 6-well. However, there are micropaleontologic determinations of the Jurassic-Cretaceous boundary formations from neighboring wells. Here the calpionellids can be correlated with ammonites and radioactive logs from several wells. The contact between the Pimienta and Lower Tamaulipas Formations was taken as reference to build the section in Figure 4. Biostratigraphic analysis showed the following results: Tanceme 101-well, core 5 (2088–2090 m): *Calpionella alpina*, *C. elliptica,* and *C. intermedia*; Encinal well-1, core 4 (2366–2369 m): *C. alpina* and *C. elliptica*; Ozuluama well-1, core 6 (2370–2372 m): *C. alpina* and *C.elliptica*; La Laja well-1, core 6 (2722–2724 m): *C. alpina* and *C. elliptica*; Rancho Nuevo 7-well, core 1 (2166–2169 m): *C. alpina* and *C. elliptica*; 3 Hermanos 133-well, core 5 (2045–2047 m): *C. alpina* and *C. elliptica*; and 3

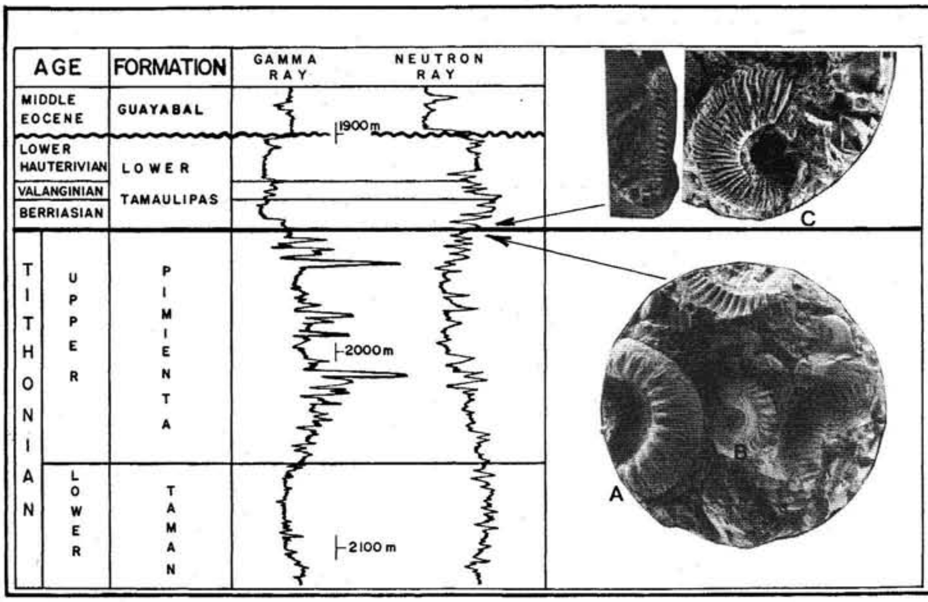

Figure 3. Jurassic-Cretaceous boundary in Bejuco 6-well, eastern Mexico, according to ammonites found in cores and gamma ray logs. Upper Tithonian with *Proniceras subpronum* Burckhardt (A) and *Salinites grossicostatu* (Imlay) (B); Berriasian with *Berriasella* (*Berriasella*) aff. *jacobi* Mazenot (C) (scale ×0.5).

Hermanos 1001-well, core 5 (2392–2396 m): *C. alpina* and *C. elliptica*: These wells were correlated by means of radioactive logs using as a stratigraphic datum the top of the Pimienta Formation, which contains ammonites from the upper Tithonian in the Bejuco 6-well. Cores from these wells, cut from a layer of the Pimienta Formation almost 50 m thick, contain *C. alpina* and *C. elliptica*. In addition to these two species, *C. intermedia* was also found in the Tanceme 101-well. The *Calpionella alpina-elliptica* association persisted in the lower Tamaulipas Formation micritic-limestones body, ~10 m thick (Fig. 4).

JURASSIC-CRETACEOUS BOUNDARY IN THE SOUTHEAST POZA RICA DISTRICT SUBSURFACE, EASTERN MEXICO

Calpionellids, ammonites, and the gamma ray curves from 10 wells in the southeast Poza Rica District, eastern Mexico, allowed construction of a section that includes parts of the Pimienta and Lower Tamaulipas formations. The abrupt contact between these two formations as seen in the gamma ray curve provided a reference to build the section. The gamma ray curve shows a strong right to left displacement from the calcareous-argillaceous and bentonitic Pimienta Formation to the micritic-limestones of the Lower Tamaulipas Formation.

The behavior of calpionellids and ammonites in the strata next to the contact between those two formations can be observed within a portion ~70 m thick in several wells from the Mesa-Grande-2 well to the Zanzapote-1 well. *Calpionella alpine*, *elliptica*, *neocomiensis*, *darderi*, *oblonga*, *carpathica*, *hispanica*, *longa*, and *cadischiana* appeared simultaneously 25 m before the upper contact of the Pimienta Formation and persisted throughout the portion and continued for another 65 m into the lower Tamaulipas Formation (Fig. 5).

A specimen of the *Salinites* ammonite was found in the Sultepec 1-well (core 2, 2150–2159 m), 25 m below the upper contact of the Pimienta Formation. *Durangites* and *Parodontoceras* ammonites were found in the last upper 5 m of the Pimienta Formation from the San Miguel del Rincon 3-well (core 3, 2940–2949 m). In the oil wells studied, no ammonites from the base of the Cretaceous were found (Fig. 5).

According to studies carried out in other parts of Mexico, an analysis of this section showed that the ammonites characterizing the upper Tithonian are present only in the top strata of the Pimienta Formation (Cantú-Chapa, 1967). Therefore, the Jurassic-Cretaceous boundary corresponds to the Pimienta and Lower Tamaulipas formations.

BIOSTRATIGRAPHIC PROPOSAL TO DEFINE THE UPPER JURASSIC–CRETACEOUS BOUNDARY BY MEANS OF AMMONITES

Researchers can utilize the ornamental and sutural elements of the berriasellid ammonites to establish zones for defining the Jurassic-Cretaceous boundary. These ammonites consist of evolute forms whose main ribs are bifurcated on the external part of the flanks and have a tabulate or rounded venter; they characterize the upper Tithonian–Berriasian group of the Subfamily Berriasellinae. The position of the ribs in the ventral region and the shape of the first lateral saddle of the suture line differentiate two groups that are located on the Jurassic-Cretaceous boundary (Fig. 6).

1. The first group comprises forms with interrupted ribs at the venter. S1 is thin and elongated or rectangular and wide,

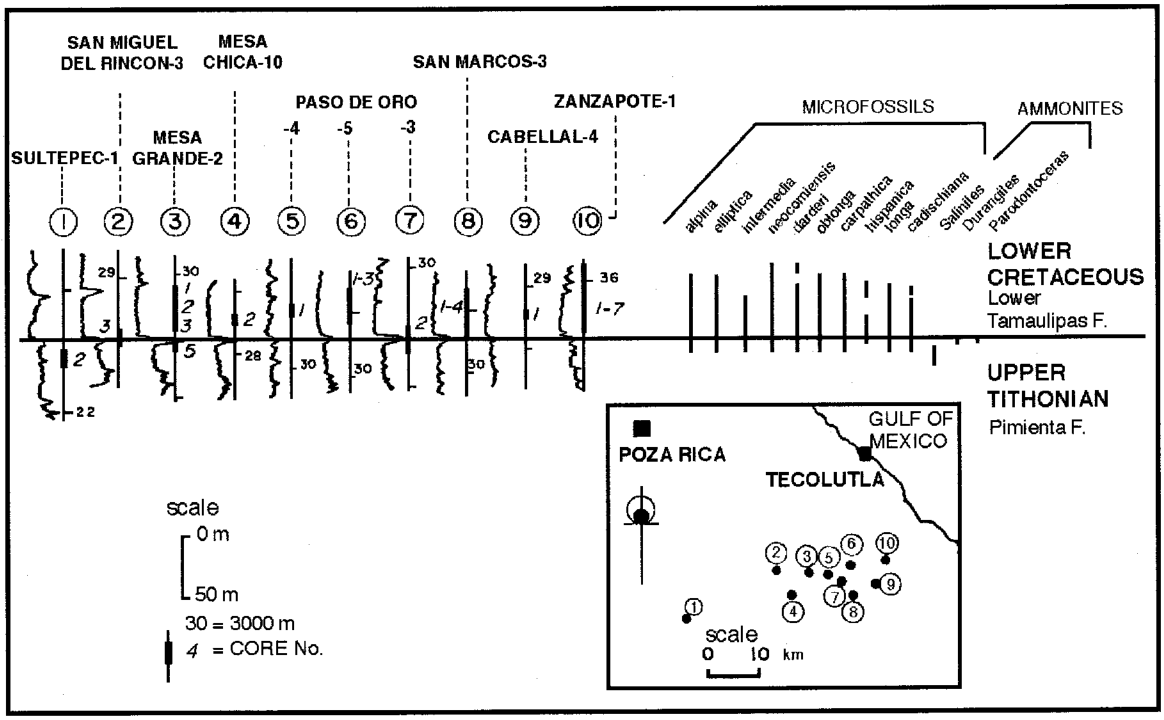

Figure 5. Jurassic-Cretaceous boundary in oil wells in Poza Rica district according to gamma-ray logs, ammonites, and calpionellids distribution. Note chronostratigraphic distribution of *Calpionella alpina* and *C. elliptica*, which cross Jurassic-Cretaceous boundary. Stratigraphic datum is top of Tithonian. F. is formation.

Mexico, where it is sometimes present in almost 70 m of Upper Jurassic strata. Some representatives of *Salinites* from Louisiana wells have also been studied and indicate an upper Tithonian age (Imlay and Hermann, 1984). Eastern Mexico has the same upper Tithonian ammonites as Argentina, Cuba, and southeastern United States, establishing correlations.

CONCLUSIONS

This study characterized the Jurassic-Cretaceous boundary in the subsurface of eastern Mexico according to paleontologic material obtained from oil well cores. It compared ammonites and microfossils to radioactive logs to place them and precisely establish their stratigraphic distribution among the neighboring sedimentary sequences.

Calpionella alpina and *C. elliptica* occur in the strata at the top of the Jurassic, right after the first occurrence of *Suarites,* which represent the base of the upper Tithonian. The age of these microfossils corresponds to the time lapse defined by the interval containing the *Kossmatia-Proniceras-Durangites-Substeueroceras* association located at the top of the upper Tithonian. These ammonite genera do not transgress the Jurassic-Cretaceous

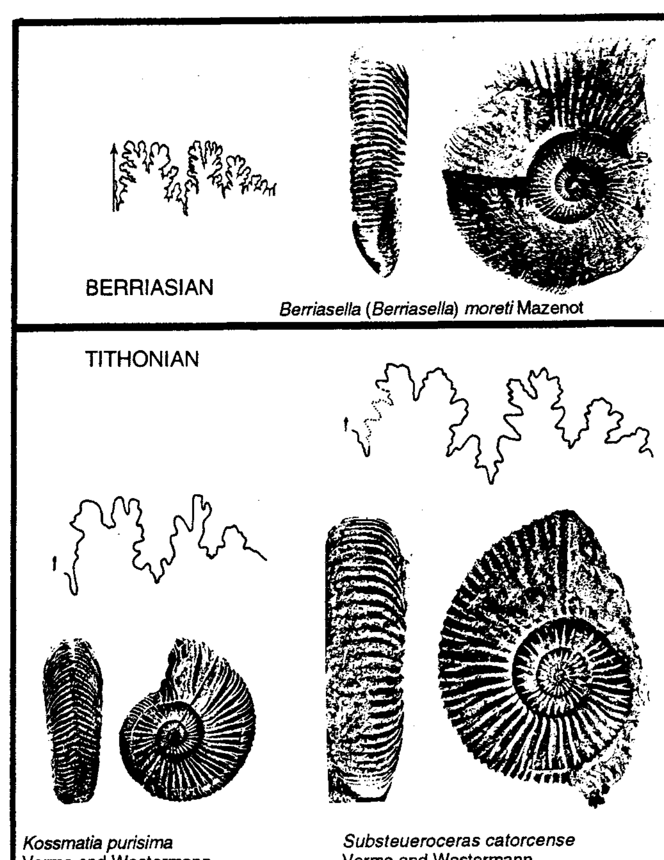

Figure 6. Jurassic-Cretaceous boundary according to suture line in berriasellids. *Berriasella* (*Berriasella*) (×0.5), *Kossmatia* (×0.5), and *Substeueroceras* (×0.5); after Mazenot (1939) and Verma and Westermann (1973).

boundary. However, calpionellids continue into the basal Cretaceous rocks. Several ammonites, *Berriasella* (*Berriasella*) aff. *jacobi*, *Subthurmannia* sp., *Spiticeras* sp., and *Neolissoceras semisulcata*, represent the base of the Cretaceous. These last fossils are more specific than *C. alpina* and *C. elliptica*, which transgress the boundary.

A strong lithologic change noticeable in radioactive logs and confirmed by core samples also characterizes the Jurassic-Cretaceous boundary in eastern Mexico. A transitional and sometimes abrupt contact between two sedimentary series, the Jurassic argillaceous limestone with bentonite and the micritic limestones of the base of the Cretaceous, also represents this boundary. The sudden evolutionary mutations in ammonites from the sedimentary sequences next to the Jurassic-Cretaceous boundary represent the time-chronostratigraphic element needed to define it throughout a large region of eastern Mexico.

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