13

Continental Evaporitic Sedimentation in Navarra During the Oligocene to Lower Miocene: Falces and Lerín Formations

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Structural Setting

Tertiary deposits of continental origin (Oligocene-Miocene) in the western sector of the Ebro Basin are found in the geographical area known as the Ribera of Navarra and La Rioja (north and south of the Ebro River, respectively). They are bounded by some very well-defined structural elements (figure 13.1). To the south, the Tertiary sediments are in contact with the Mesozoic of the Cameros Chain (Iberian Range) along major reverse faults having several hundred meters of slip. Along these structures the Tertiary rocks are tilted almost vertically and are even overturned. To the north, the contact also is along reverse faults. The affected sediments are mainly made up of the marine Eocene of the Pamplona Basin, which separates the Ribera zone from the Pyrenees. Riba (1964) called those structural lines confining the continental Tertiary "master faults," and pointed out their important syn-sedimentary role in the configuration and later subsidence of the basin during the Oligocene and Miocene. Across these master faults a series of transverse structures is superposed to the first set, which acted as wrench-faults and have a normal orientation.

In the inner part of the basin the Tertiary sediments show only gentle fold structures with axes trending ESE-WNW. These folds disappear towards the west and the southeast, giving way to a flat (tabular) landscape almost unaffected by any tectonism. On those folds that are present, the axes are sometimes deformed or display sudden periclinal ends, because they commonly involve evaporitic formations. Deformation intensity decreases towards the south and the age of the folds becomes progressively younger in that direction as well.

Sedimentation during the Oligocene and Miocene took place under a compressive regime controlled by the uplift and structural evolution of the Pyrenees and the Iberian ranges. Between these ridges, the sedimentary troughs gradually shifted toward the south as a result of the predominance of the Pyrenean deformation over the Iberian one. This continuous shift is exactly paralleled by the migration of the evaporitic formations that generally occupied the basinal depo-axis (figure 13.2). The same observation is demonstrated by the shift in clastic provenance (Riba and Pérez Mateos 1962). In the Eocene to early Oligocene, the paleocurrents came generally from the south (Iberian Range), while during the late Oligocene, and particularly during the Miocene, they displayed preponderantly Pyrenean provenance.

Busson, G. & Schreiber, Ch. eds., Sedimentary deposition in rift and foreland basins in France and Spain (Paleogene and lower Neogene). Columbia University Press, New York, 1997.

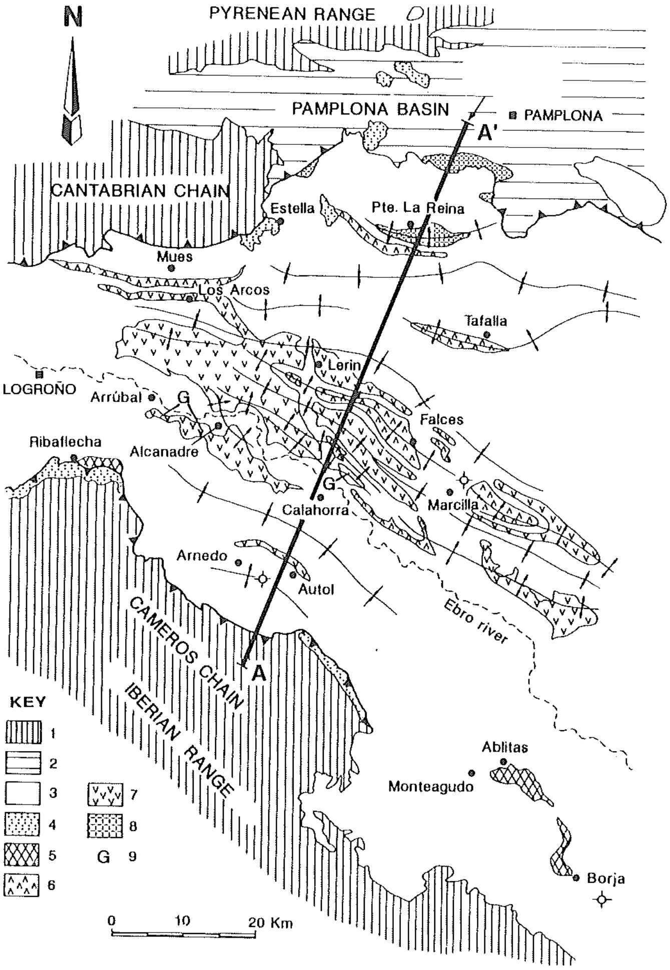


FIG. 13.1. Geological map of the Navarra-La Rioja sector of the Ebro Basin. The position of the outcropping evaporitic formations and the deep boreholes is shown. Section A–A′ is given in figure 13.2. Key: 1 = Mesozoic; 2 = marine Tertiary; 3 = continental Tertiary, detrital and calcareous; 4 = Triassic diapirs (Keuper); 5 = Monteagudo and Ribafrecha Gypsum formations; 6 = Falces Gypsum Formation; 7= Lerín Gypsum Formation; 8 = Puente La Reina Gypsum Formation; 9 = glauberite in the Lerín Formation.

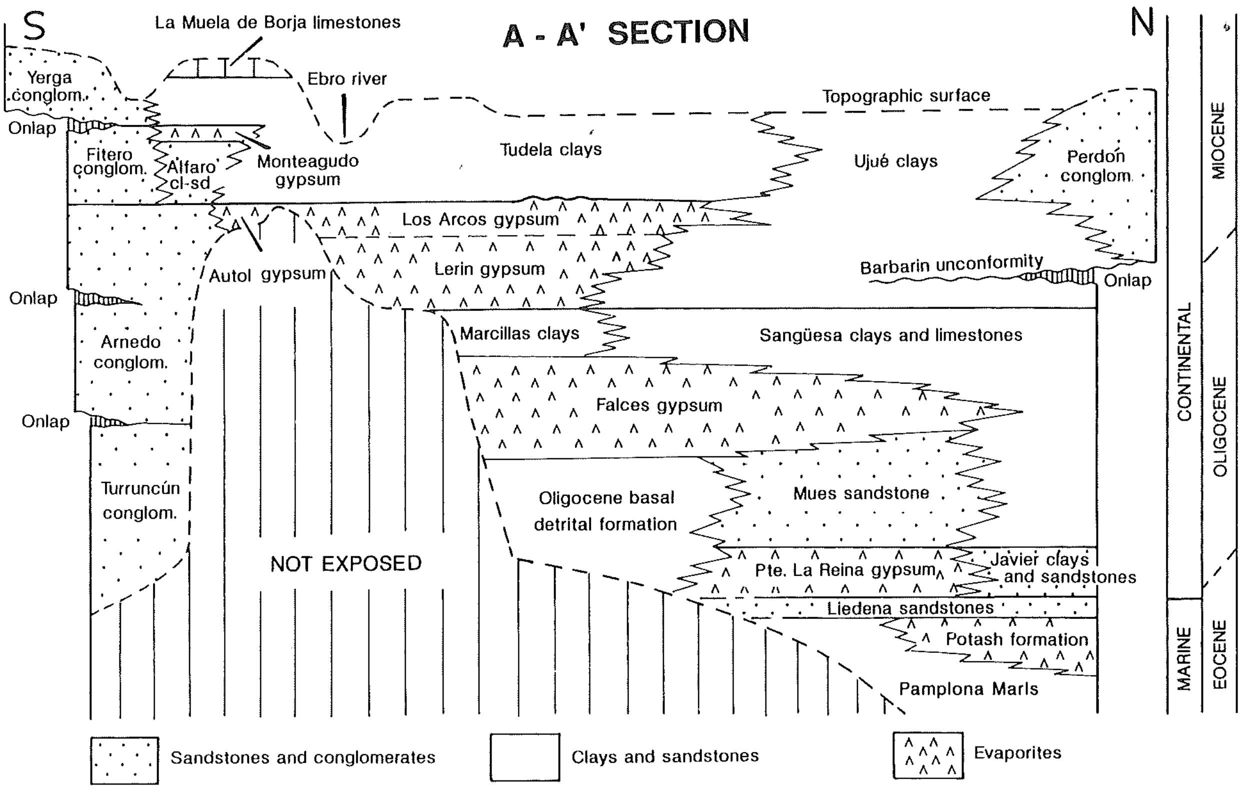


FIG. 13.2

Stratigraphical Setting

In the continental Tertiary sequence a marked distinction is seen between those coarse-clastic materials (conglomerates and sandstones) of the basin borders and the fine-detrital and chemical-evaporitic sediments of the central areas (clays, sulfates, and chlorides). The former are represented by proximal alluvial fans, while the latter consist of playa lake deposits initiated on the distal argillaceous plains of those fans. Calcareous lacustrine facies are of lesser importance and are variably developed depending on the sectors and history of basin evolution.

BASIN CENTER

The general stratigraphic characteristics of the basin center are known from studies by Riba and Pérez Mateos (1962), Riba (1964), Crusafont et al. (1966), Castiella et al. (1978), Solé (1972), Ortí et al. (1986), Ortí and Salvany (1986b), Salvany (1989a, 1989b), and Riba and Jurado (1992). The continental Tertiary sequence is up to 4,000 m thick and consists mainly of alternating detrital and evaporitic formations displaying very complex lateral facies distribution. During the Oligocene three major evaporitic units were deposited: the Puente la Reina Gypsum, the Falces Gypsum, and the Lerín Gypsum (Castiella et al. 1978). Other minor evaporitic formations were deposited during the Miocene at the southern border of the basin. The Puente la Reina Gypsum directly overlies the top of the Eocene marine sediments (Guendulain Formation). This unit constitutes the basement of the continental Teriary in the northern part of the Navarrese sector of the Ebro Basin. The Puente la Reina Gypsum is poorly known because of meager outcrops and deformed exposures. The total thickness is estimated to reach between 300 and 400 m. The evaporites are largely composed of calcium sulfate (secondary gypsum with anhydrite having both nodular and laminated lithofacies); however, some halite is present.

Overlying the Puente la Reina Gypsum is a thick detrital unit, the Mués Sandstone Formation, that reaches thicknesses between 2,100 and 2,400 m in the Los Arcos sector (Solé 1972). This formation and its laterally equivalent units represents a prolonged period in which alluvial and calcareous lacustrine facies were deposited. The age of this detritic phase is attributed to the middle Oligocene, and may be due to a relatively humid period.

The Falces Formation constitutes the second major evaporitic unit, in which the depositional area clearly expanded and overstepped a great part of the basin. This thick unit overlies the Mués Formation in the Los Arcos sector but to the south is deposited on the "Oligocene basal detrital formation" (ENRESA 1987). In this southern zone the base of the Falces Formation constitutes a planar base that is the décollement horizon for the whole fold structure of the Navarrese Oligocene and Miocene.

The uppermost of the three gypsum formations, the Lerín Gypsum, is separated stratigraphically from the Falces Formation by a detrital unit whose thickness and facies development varies in each sector of the basin. In the central part this unit constitutes a monotonous argillaceous sequence 300 to 400 m thick, with some sandstone layers and minor amounts nodular gypsum (Marcilla Clay Formation). To the north and northeast these clays change laterally into more detrital argillites (Sangüesa Formation), an intercalation of common sandstone and limestone layers reaching thicknesses of 650 m with a 1,250 m maximum.

The Lerín Formation is considered to lie at the Oligocene-Miocene boundary (figure 13.2), but this age assignment is somewhat uncertain because of the lack of vertebrate remains within these

FIG. 13.2. Lithostratigraphic schema, without scale, of the detrital and evaporitic formations of the Navarra-La Rioja sector of the Ebro Basin, drawn in a north-south profile.

facies. Nevertheless, several paleontologic findings (Cuence et al. 1992) have suggested an age that is entirely Miocene for the Los Arcos unit and all the sediments overlying the Lerín Formation.

The Miocene materials overlying the Lerín Formation are a thick clayey sequence built up of red argillites, the Alfaro and Tudela Clay formations, which extensively crop out in the southern half of the Ribera de Navarra and La Rioja. Both represent the fine detrital sedimentation in the central area of the western Ebro Basin. The Alfaro Clay, which is well developed to the southwest of the Ribera, contains numerous sandstone layers and represents a fluvial system coming from the west. The Alfaro Clay passes laterally into the Tudela clay (argillites with some limestones and sandstones), well developed in the southeast. The Tudela Clay, with thin layers of interfingering lacustrine carbonate, was deposited by a fluvio-lacustrine system that represents an intermediate facies assemblage between the Alfaro Clays and the Zaragoza Formation that lies at the center of the Ebro Basin (figure 8.3, this volume). The Alfaro amd Tudela Clays contain small, local intercalations of gypsum, the only evaporitic vestiges within these detrital and calcareous formations. To the north, the Alfaro and Tudela formations pass laterally into the Ujuè Clays that represent the distal alluvial facies coming from the Pyrenees (figure 13.2).

The Tertiary sequence ends with limestone units (La Muela de Borja Formation) that are algal and bioclastic limestones, intensively burrowed, containing gastropods and ostracods and are a few tens of meters thick (maximum 30 to 40 m).

BASIN BORDERS

The southern border of the basin is well known because of several significant studies (Bomer, 1954; Riba, 1955; Muñoz et al. 1986/1987; Pérez et al. 1988; Muñoz 1992; and Riba and Jurado 1992). They all point out the importance of the tectonic control exerted by the Iberian Range on the detrital sediments during the Paleogene and Neogene. In the Arnedo sector six tecto-sedimentary units have been identified by Muñoz et al. (1986/1987). These tecto-sedimentary units ("Unidad Tecto Sedimentaria" or UTS) are limited by sedimentary breaks that appear as unconformities on the basin borders and/or as significant changes in lithologies in the general sedimentary trends in the basin center (figure 13.3).

In these sequences, conglomeratic horizons represent maximum development of alluvial systems, implying significant clastic input due to orogenic activity. Deposition of evaporites and/or carbonates marks periods of lesser tectonic activity allowing maximum expansion of lacustrine environments. Clastic sequences generally coarsen upward marking the uplift phases of the development of the Iberian Range. However, in some sequences fining upwards trends were developed.

Passing toward the center of the basin there is a very rapid lateral change from the clastic facies into evaporites. In only a few kilometers a marginal conglomeratic sequence passes into a sandy and argillaceous sediment, and almost immediately develops into argillaceous-evaporitic sediments. At the same time, angular unconformities present on the borders attenuate towards the basin and completely disappear in its center, where the contacts between the various formations always seem concordant. In the entire evaporitic assemblage, only the youngest member can be directly correlated with detrital equivalents at the borders.

The most significant of the unconformities noted in this section was developed near the top of the Monteagudo Gypsum. The Miocene sequence overlying it extends broadly to the south, even covering the Mesozoic section of the Cameros Chain. At its contact with the lower Miocene conglomerates, an angular unconformity is noted.

The stratigraphic characteristics of the northern border of the basin appear more complex and are poorly known. Nevertheless, articles by Riba and Pérez Mateos (1962) and Riba (1964, 1992) have explained the tecto-sedimentary behavior of that border and identified an important angular unconformity (Barbarin discordance) inside the detrital sequence that separates the Falces and the Lerín formations. This unconformity disappears towards the basin center but displays a noticeable continuity along the northwestern border of the basin, over

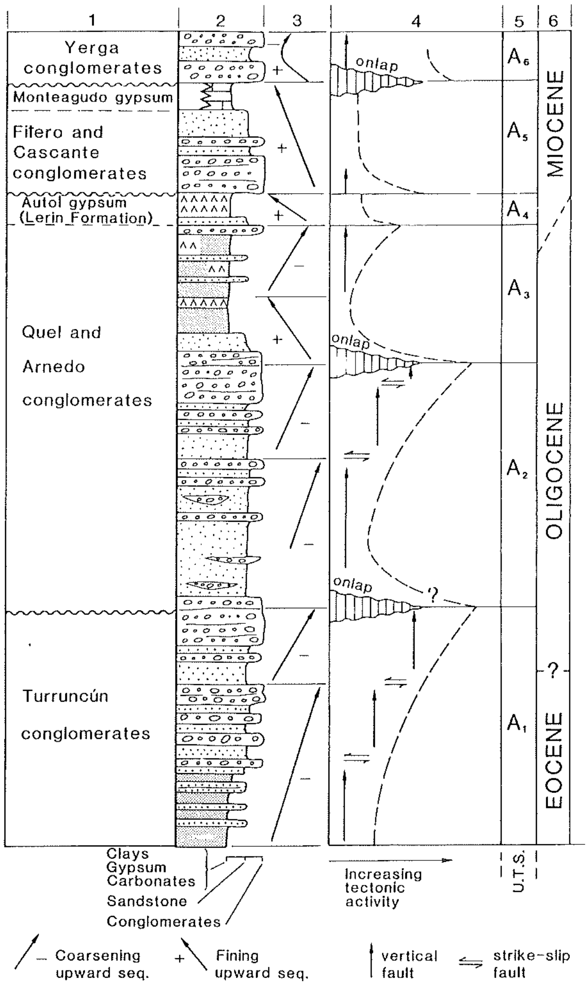


FIG. 13.3. Lithostratigraphic sequence of Paleogene and Neogene materials of the southern border of the Ebro Basin in the Arnedo (La Rioja) sector, modified from Muñoz et al. (1986/87). Key: 1 = lithostratigraphic units; 2 = lithologies; 3 = sedimentary cycles; 4 = tectonic evolution of the basin; 5 = tectono-sedimentary units (U.T.S.); 6 = chronostratigraphic units.

tens of kilometers. This Oligo-Miocene unconformity separates a lower folded sequence from a less disrupted but folded upper one, which onlaps the Mesozoic and marine Eocene materials of the south Pyrenean basin (Ujué Formation and the Perdón Conglomerates).

Falces Gypsum

Although the Falces Gypsum Formation displays sedimentological and petrological characteristics identical to the overlying Lerín Gypsum Formation, it is poorly known because of limited area of outcrop. The Falces Gypsum Formation is a very thick evaporitic unit that always occupies the highly deformed cores of diapiric anticlines while the Lerín Gypsum normally forms their flanks, which are far less affected by tectonism.

Because of its position within diapiric structures it is quite difficult to estimate the true thickness of the formations. In Desojo (near Los Arcos), where this unit is completely exposed, the beds are almost vertical and the gypsum is between 750 and 950 m thick (Solé 1972). On the core of the Falces anticline, the Marcilla borehole was drilled through the Falces Formation, and a diapiric thickness of 2,800 m was present (IGME 1987). The true sedimentologic thickness may be about one thousand meters.

At the surface the Falces Gypsum is a monotonous sequence of secondary gypsum layer and common gray argillite fine intercalations. The gypsum lithofacies are composed mainly of the laminated-nodular (L-N) association (see chapter 8, this volume). In the Marcilla borehole the calcium-sulfate is always anhydrite, with significant amounts of intercalated halite. Some glauberitic beds (see chapter 14, this volume) have been recognized in cores of the Marcilla borehole, displaying features similar to the glauberite of the Alcanadre deposits of the Lerín Formation (Salvany and Ortí 1994).

In the Marcilla borehole, which lies at the center of a diapiric anticline, the following lithologic members were described, from base to top (ENRESA 1987):

1. lower anhydrite member (296 m thick)
2. lower anhydrite-halite member (333 m thick)
3. lower member with anhydrite and gray clays (171 m thick)
4. intermediate anhydrite-halite member (389 m thick)
5. intermediate anhydrite member (357 m thick)
6. upper member with anhydrite and gray clays (215 m thick)
7. upper anhydrite member (1004 m thick)

Carbonates are almost completely lacking in the Falces Formation. The clays present are a mixture of illite, chlorite, and kaolinite.

Lerín Gypsum

This formation is a complex evaporitic formation made up of alternating gypsiferous and clayey units displaying significant lateral facies changes (Salvany 1989). Generally it is made up of five major gypsum units of great lateral continuity, separated by argillaceous units of thicknesses similar to the gypsiferous ones. The gypsum units show a clear thickening upward tendency, and each unit expands over the underlying one and shifts toward the west (figure 13.4 and 13.5).

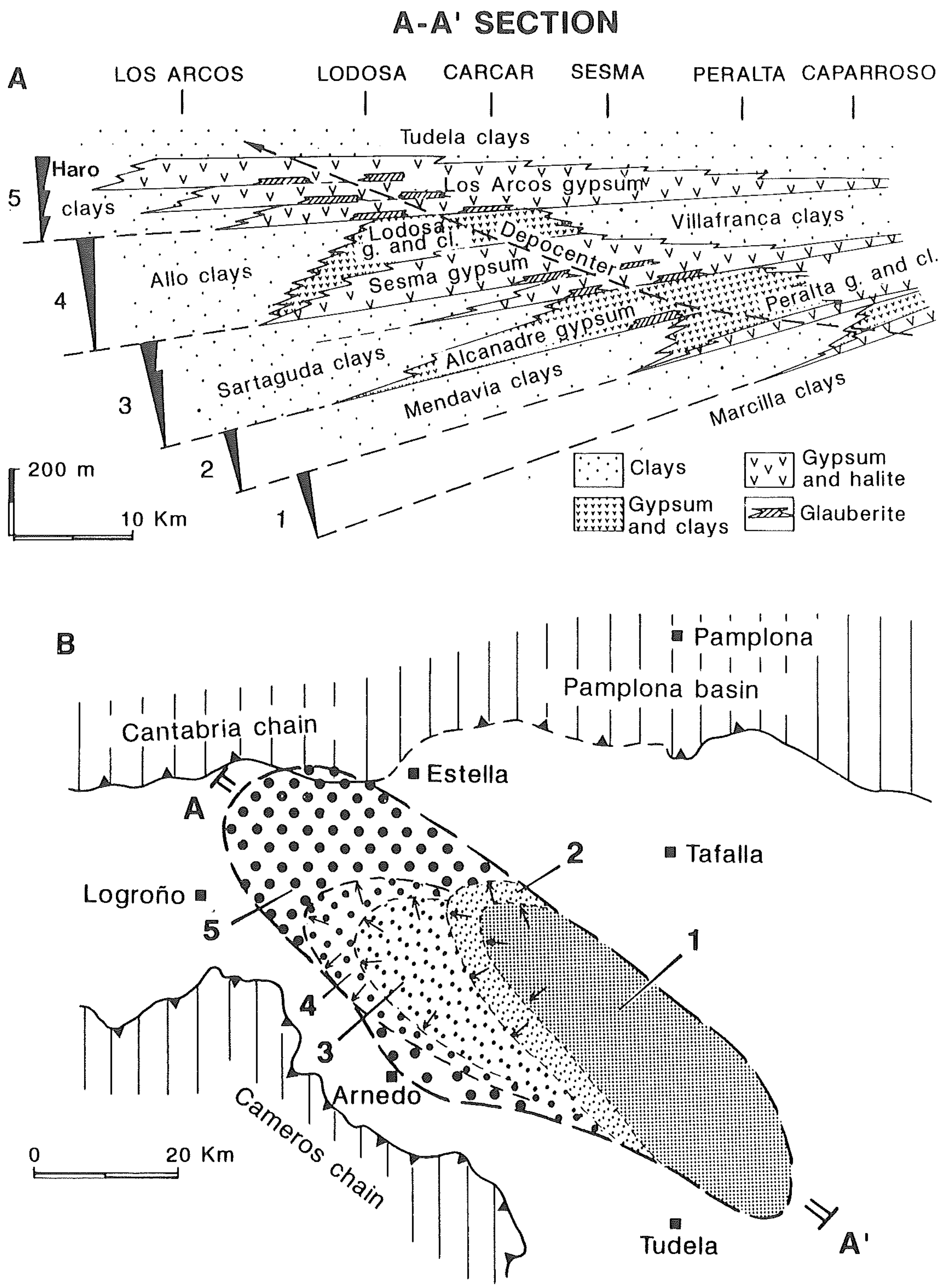
The most important gypsum level in the Lerín Formation is the uppermost one (Los Arcos Gypsum) located in the central part of the basin, reach 250 m thick and more than 100 km long. To this unit belong the glauberite deposits of Alcanadre-Arrúbal (chapter 14 this volume). Toward the southern border of the basin this gypsum deposit passes into the Autol Gypsum, characterized by the presence of alabaster meganodules scattered within a micronodular matrix that was formed by replacement of the microlenticular primary gypsum. The characteristics of the Autol Gypsum are very similar to those of the Monteagudo and Ribafrecha gypsums (see Ortí and Salvany in this volume).

Clay horizons interlayered between these five gypsum units also contain minor gypsum layers and a small amount of sandstone. The development of these gypsum layers varies from region to region. In the marginal part of the formation they are rare (Allo, Sartaguda, Mendavia, and Villafranca units), but in the central part they give way to gypsum-clay alternations (Lodosa and Peralta units).

The gypsum and clay units formed as couplets made up of a basal gypsum unit and an overlying clay-gypsum unit that represent an "evaporitic megacycle" (Salvany 1989). The megacycles show the broadest areal coverage by the evaporites at the base; moving up through each sedimentary cycle, the detrital (clayey) phase invades the evaporite area resulting in reduction of the evaporative area. During this later period the detrital sediments cover a very broad area, extending from the margin to the center of the basin. The most saline facies (laminated gypsum halite and glauberite) are found near the center of the basal gypsiferous units. Toward the top and the margins these megacycles are solely composed of nodular anhydrite with rare laminated gypsum (now as secondary alabastrine gypsum), within an argillaceous matrix.

These megacycles may be interpreted as both the result of changes in the rate of subsidence or due to long-term climatic fluctuations. (1) When the subsidence was slow, the alluvial facies were restricted

Fig. 13.4. Lithostratigraphic subdivison of the Lerín Formation: A. Northwest-southeast section; B. Plan view showing the mega-sequence structure. Key: Numbers 1 through 5 indicate correlation of megacycle succession indicated in figure 13.4A. Arrows indicate migration direction of depocenter.



A-A' SECTION
A
LOS ARCOS
LODOSA
CARCAR
SESMA
PERALTA
CAPARROSO
Tudela clays
Haro clays
Los Arcos gypsum
Villafranca clays
Lodosa g. and cl.
Depocenter
Allo clays
Sesma gypsum
Peralta g. and cl.
Alcanadre gypsum
Sartaguda clays
Mendavia clays
Marcilla clays
5
4
3
2
1
200 m
10 Km
Clays
Gypsum and halite
Gypsum and clays
Glauberite
B
Pamplona
Pamplona basin
Cantabria chain
Estella
A
Tafalla
Logroño
Arnedo
Cameros chain
Tudela
A'
0
20 Km

FIG. 13.4

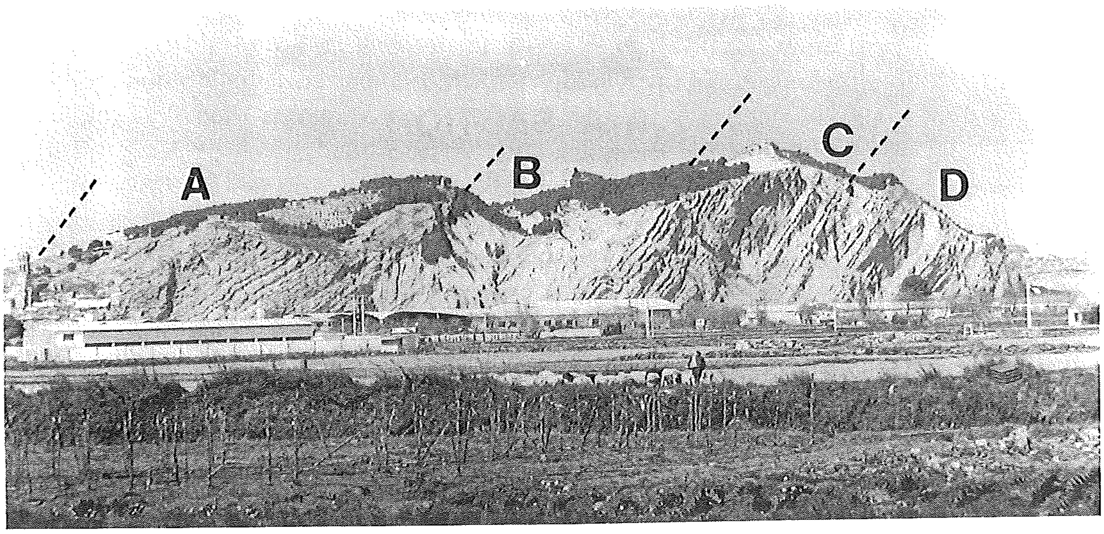


Fig. 13.5. Panoramic view of Lerín Gypsum Formation in the village of Peralta (Navarra), as seen on the southern flank of Falces anticline (see figure 13.1 for location). Key: A = Los Arcos Gypsum; B = Villafranca Clays; C = Sesma Gypsum; D = Peralta Gypsum and Clay (these units are located in figure 13.4).

to the basin margins, and the evaporites became well developed toward the center of the basin, with little detrital influx. When the rate of subsidence increased, the marginal alluvial systems grew and their distal systems expanded to the basin center, preventing the development of evaporites. (2) During a dry period, the alluvial facies were restricted to the basin margins with evaporites toward the basin centers. However during a wetter period there was a greater influx of water, building extensive alluvial systems and flooding the basin center with less concentrated water.

Therefore from the Marcilla Clays to the Los Arcos Gypsum the sedimentary evolution shows a progressive increase in the evaporite/detrital ratio, which may be the result of either progressive tectonic quiescence or deposition during a drier portion of the climatic cycle.

Sedimentary Facies

GYPSUM/ANHYDRITE

Three calcium sulfate lithofacies (anhydrite at depth and secondary meteoric-sourced gypsum after anhydrite at surface) characterize most of the gypsum units:

Nodular and enterolithic facies. This is the dominant lithofacies in the Falces and Lerín formations. Nodules display various forms, and their sizes range from 1 or 2 cm to 20 or 30 cm in diameter (figure 13.6). Layers of nodular facies may reach thicknesses up to one meter, in which the host matrix is clay or dolomicrite. These appear to be typical continental sabkha facies. They are present in all stratigraphical sections, and particularly in the marginal part of each gypsiferous unit, where they may be the only facies present.

Laminar facies. In this facies, gypsum or anhydrite forms layers having a millimetric lamination, but some morphologic variations are present (figure 13.7). These laminar layers may accumulate into thicker horizons (up to several meters) in which nodular levels, mainly of the enterolithic type, may be intercalated. The sedimentary structures are perfectly preserved and display such features as wave-ripple lamination and undulations of likely algal origin. No pseudomorphs of selenitic gypsum are found in this facies.

Lenticular facies. Some gypsum layers are made of aggregates of lenticular gypsum crystals, up to 2

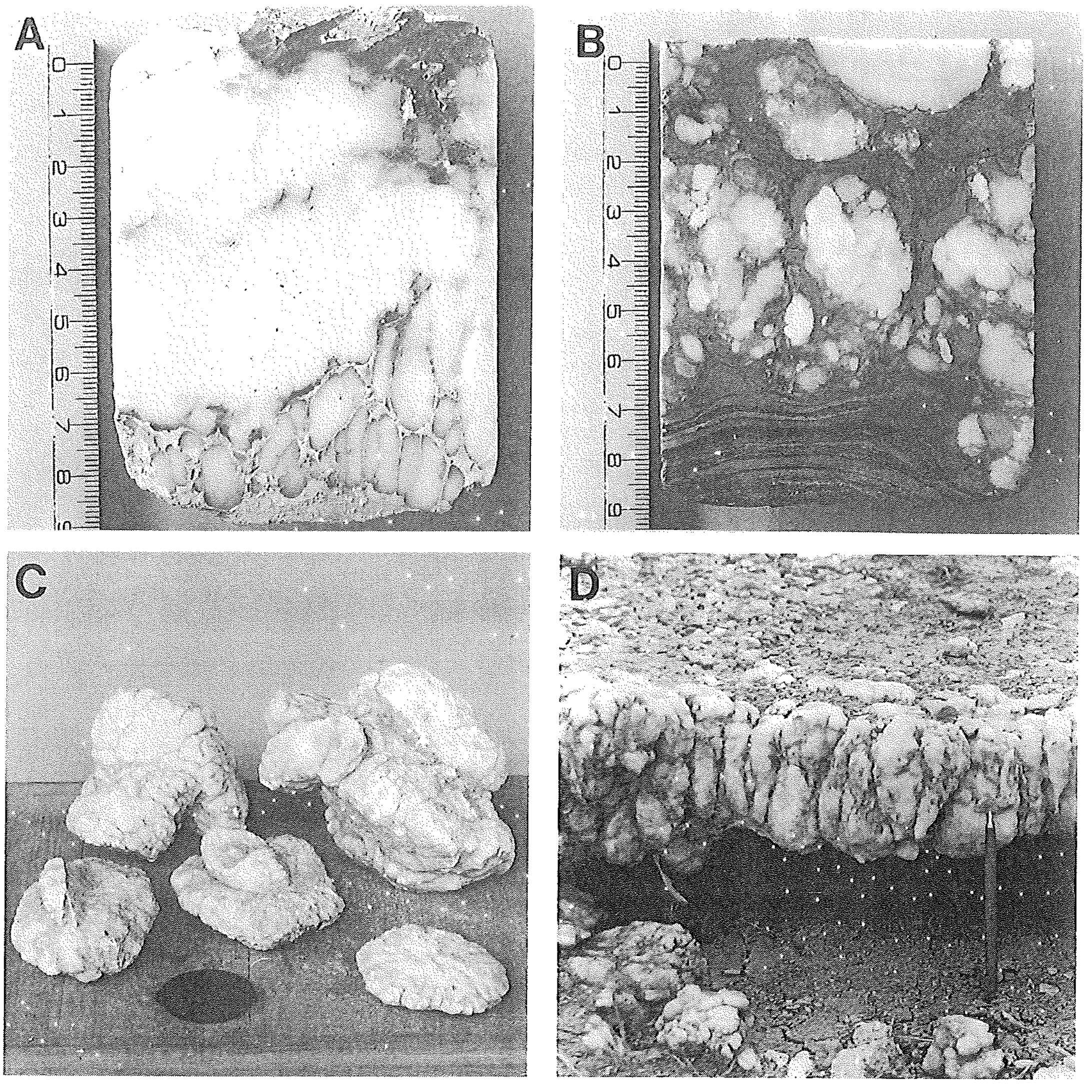


Fig. 13.6. Photographs of various morphologies of nodular lithofacies in the Falces and Lerín formations. A. Massive nodular anhydrite; B. Nodular anhydrite within an abundant calcareous (dolomicrite) matrix; C. Single or composite gypsum nodules, which are arranged scattered within clay horizons; D. Vertically elongated fabric in the horizons of gypsum nodules intercalated in the clay layers.

or 3 cm long, preserved as pseudomorphs and composed of polycrystalline secondary gypsum. These layers are usually intercalated within the laminated lithofacies. Such aggregates are also present within the carbonate beds where the individual pseudomorphs are generally smaller than 1 cm.

HALITE

Halite, a common mineral of the Falces and Lerín formations, is preferentially associated with the major gypsum horizons, but it is never seen on exposure because of its high solubility. In boreholes

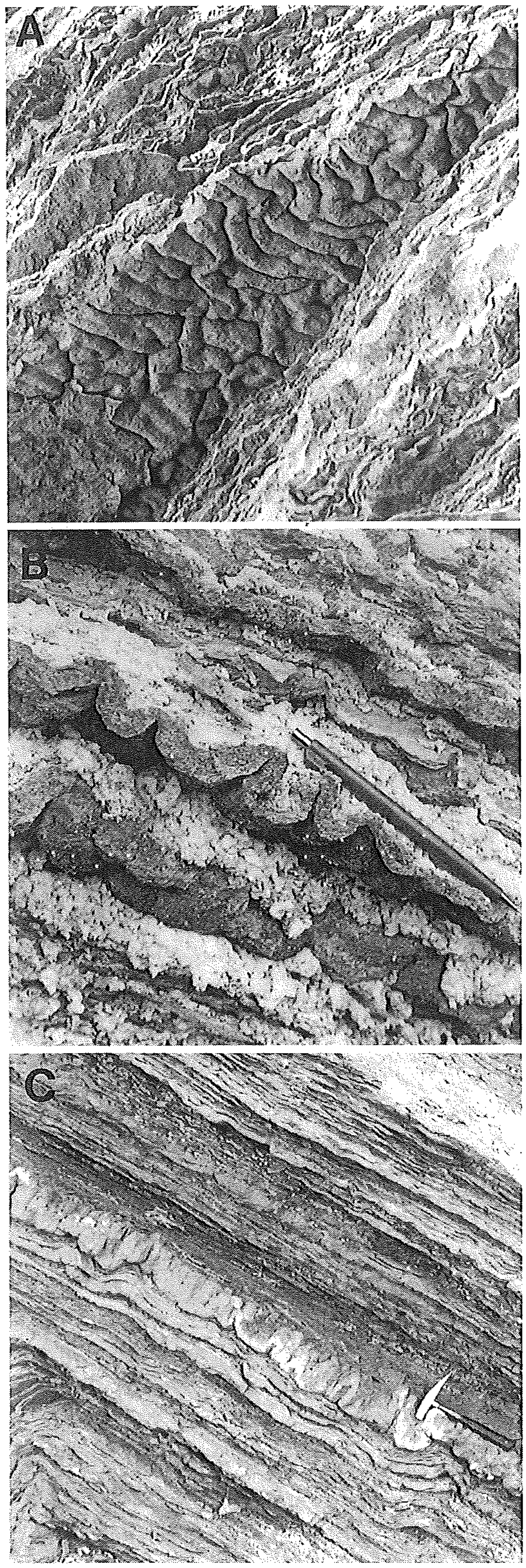


Fig. 13.7. Various morphologies of laminated gypsum in the Falces and Lerín formations. A. and B. Two aspects of the laminated gypsum layers showing undulating morphologies that apparently originate from stromatolitic control, intercalated within the major horizons of laminated gypsum (note pencil); C. Characteristic appearance in outcrop of a laminated gypsum layer within the Lerin Formation. Intercalations of enterolithic horizons are a normal feature of these laminated gypsum beds (note hammer).

this mineral forms beds several meters thick displaying an internal banding in which alternation with gypsum-anhydrite and argillaceous layers is common. Bromine content is extremely low in the halite (between 2 and 10 ppm), appropriate to its continental origin.

CARBONATE

There is very little carbonate in the Falces and Lerín formations mainly as dolomite. In some areas the carbonate thickens and is present as beds less than 1 meter thick within the gypsum sequences, but, in general, the carbonate intercalations are only a few centimeters thick. Such layers may be featureless mudstones (argillaceous dolomicrite) that locally contain evaporites (lenticular and micronodular gypsum). In other places the carbonate is a matrix for gypsum nodules, or forms as millimetric alternations with laminated gypsum. In glauberite deposits, carbonate is present as dolomite and magnesite.

CLAYS

Clays, in general, display a remarkable mineralogical homogeneity, regardless of the coloration they exhibit. They are composed, variously, of illite, chlorite, and kaolite, to which micritic calcite and/or dolomite is variably associated. In the Autol Gypsum (at the southern edge of the basin), the smectite content is high (Inglès et al. 1994).

SANDSTONE

Sandstones when present are always very well sorted and fine-grained. They display tabular layers with a thickness of less than half a meter or are developed within channels (1 to 1.5 m deep). Climbing ripples, flat pebbles, and load casts are frequent. These layers are intercalated inside the principal argillaceous horizons. The mineralogical composition is mixed but is mostly siliciclastic (quartz, feldspars, micas, metamorphic, and igneous rock fragments).

Lithologic Cyclicity

The lithologic assemblage composing the evaporitic units of the Falces and Lerín formations are usually arranged in sedimentary cycles that may be single or complex and have been called "elemental cycles" by Salvany (1989). Such cycles are well developed in the mixed argillaceous-gypsiferous units such as in the Peralta and Lodosa units (figure 13.8). In these units the cycles are diversified, but in general may be considered to fall into two principal patterns:

1. *Sabkha type* (figure 13.9A). This cyclic pattern is particularly well-developed in the peripheral zones of each evaporitic unit. A lower clayey horizon is present, which includes sandstone intercalations and gypsum nodules. The nodules are frequently scattered inside the clays in an irregular manner, but also give way to nodular horizons a few cm thick. The upper horizon is made up of a well-defined nodular gypsum layer with variable proportions of clay matrix. Such cycles are interpreted as the result of sedimentation and syngenetic evolution on an exposed mud flat with the deposition of interstitial evaporites and where the water table rarely reaches the surface (Salvany 1989).

2. *Evaporitic lake type* (figure 13.9B). This pattern of sedimentation is developed in the central part of the evaporitic units. The typical lake cycle involves three horizons: (a) a lower clayey horizon in which sandstone layers and scattered gypsum nodules are intercalated; (b) an intermediate carbonate member, which is formed by dolomitic beds either interlayered with gray argillites or a calcium sulfate horizon made up of a nodular lithofacies; and (c) a calcium sulfate horizon, in which the lower part is nodular and the upper part is mostly laminated with some enterolithic intercalations. Commonly the calcareous member (b) is lacking or limited to matrix material distributed between the gypsum nodules. This cycle (the salina cycle of Ortí and Salvany, 1986) is the result of the progressive establishment of a shallow evaporitic lake on a mud flat (figures 13.10 and 13.11).

These sedimentation cycles are also present within the gypsiferous and clayey units, but in these cases they can be difficult to recognize. In the gyp-

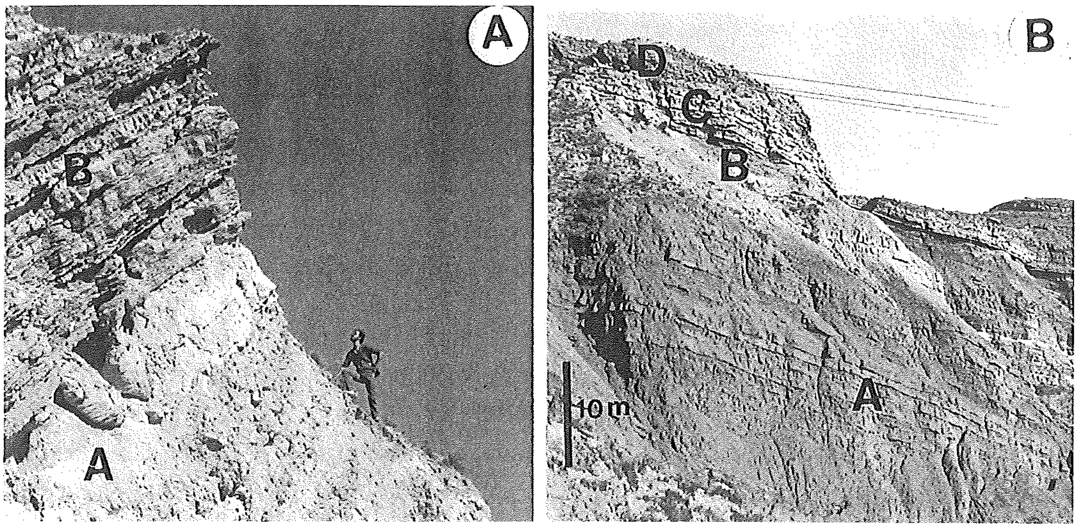


FIG. 13.8. Details of the Lerín Formation seen on outcrop. A. View of a sabkha cycle type in the Peralta unit; Key: A = clays with gypsum nodules that are either scattered or form discrete layers, B = nodular gypsum giving way to well-stratified discrete layers. B. View of an evapoiritc lake cycle type in the Lodosa unit (40 m, base to top); Key: A = clays with some sandstone intercalations; B = clays with calcerous intercalations bearing some gypsum nodules; C = dolomitic bed with intercalations of nodular gypsum; D = laminated and nodular gypsiferous beds.

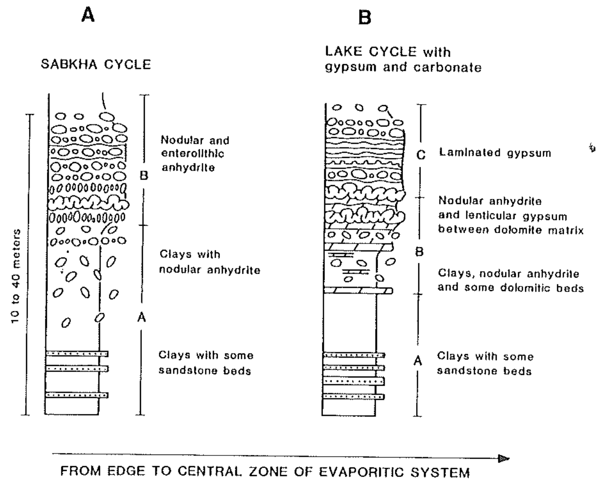


FIG. 13.9. Idealized evaporitic cycles recognized in the Falces and Lerín Gypsum formations.

sum units such elemental cycles are only composed of gypsum and no clear clay horizons are present. The gypsum units appear as thick sequences of elemental cycles showing nothing but a monotonous succession of laminar and nodular gypsum. The clayey units are made of a succession of clayey horizons with minor development of gypsum facies and/or rare nodular gypsum layers.

The cyclic succession pattern formed by the lithofacies development within the Lerín and Falces evaporites are illustrated in figures 13.10 and 13.11. The evaporites developed within the playa lake environment are made up by the development of three depositional zones with the following facies associations:

the internal zone, with facies composed of laminar gypsum and halite, developed within areas of shallow

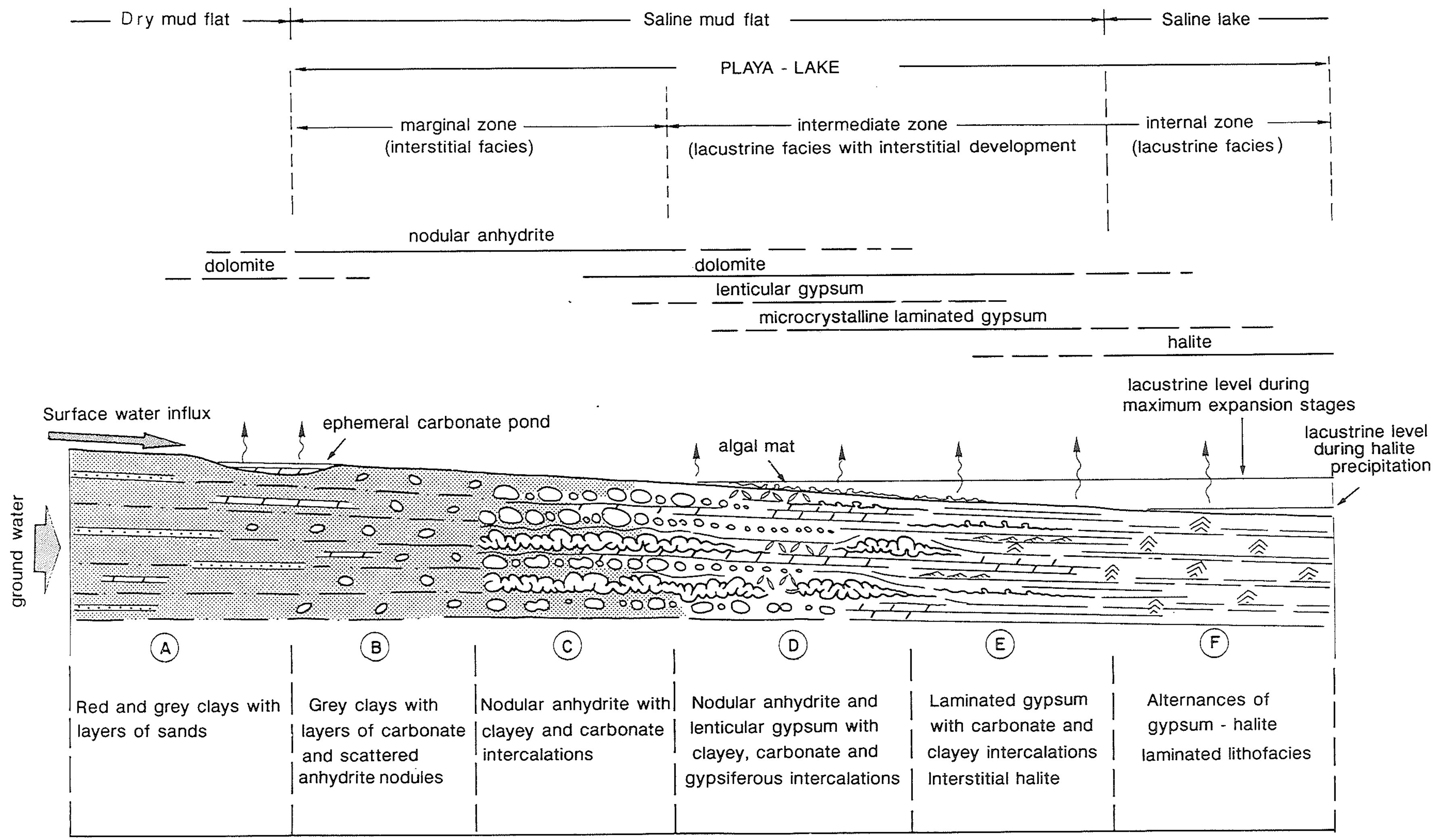


FIG. 13.10. Interpretative playa lake environment during a single depositional stage, developed from the facies distribution in the Falces and Lerín Gypsum formations.

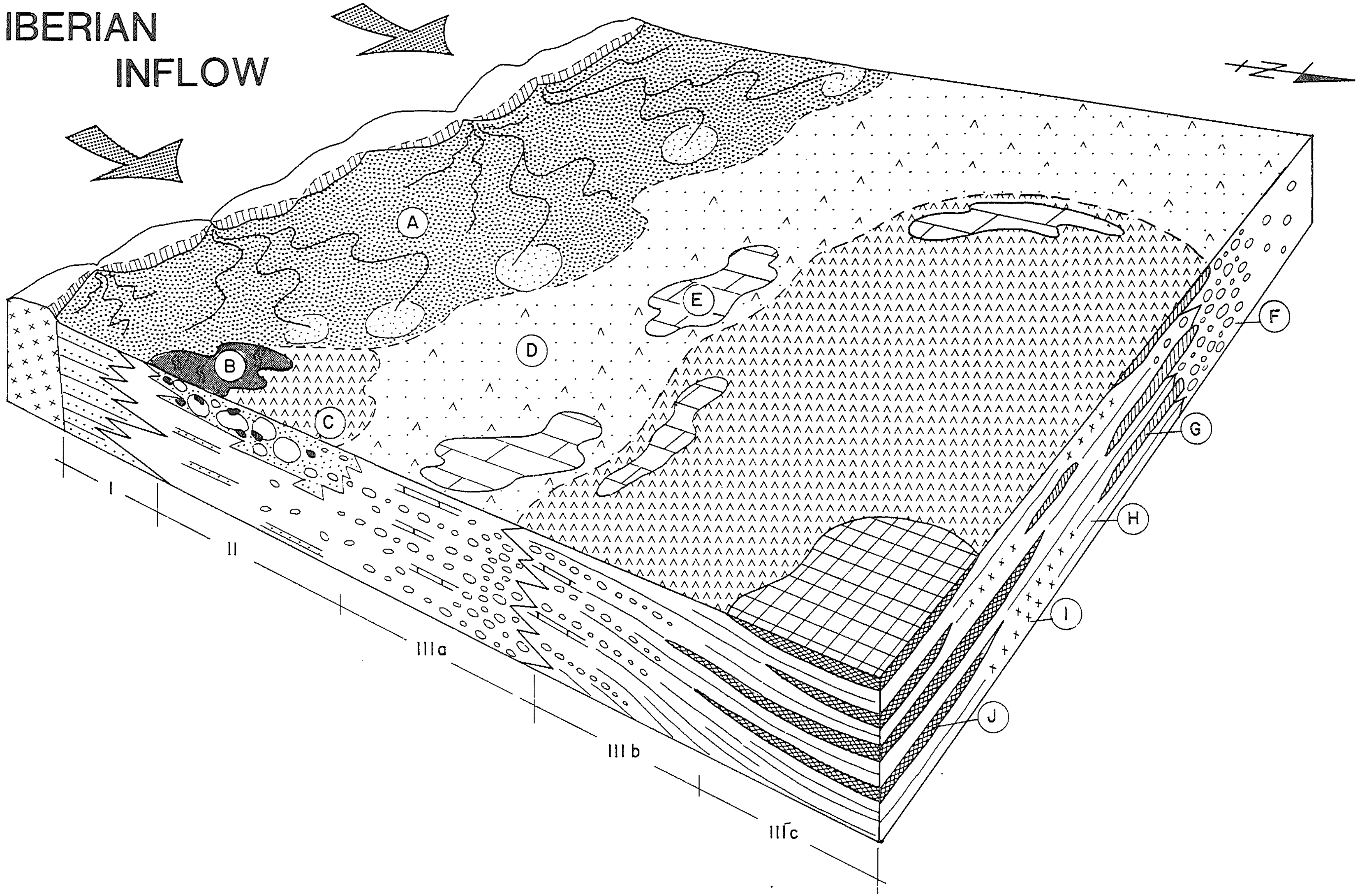


FIG. 13.11. Three-dimensional diagram showing detrital and evaporitic facies distribution for the Lerín Formation (Autol and Los Arcos units) from the southern border toward the center of the Ebro Basin. Key: I = alluvial fan zone; II = distal alluvial plain zone with marginal evaporites (Autol Gypsum unit); III = playa lake zone (IIIa = marginal zone, IIIb = intermediate zone, IIIc = internal zone). A = conglomerates, sandstones, and clays; B = lenticular gypsum with burrows and chert nodules; C = nodular and meganodular anhydrite with chert nodules; D = clays with interstitial nodular anhydrite and carbonates; E = carbonate; F = nodular anhydrite; G = glauberite; H = laminated gypsum; I = polyhalite; J = halite.

lacustrine sedimentation. During the high salinity stages halite is precipitated, and during phases of lower salinities the predominant precipitate is gypsum.

the intermediate zone, with the facies composed of laminar gypsum developed during the lacustrine phases, and nodular anhydrite or lenticular gypsum during the sabkha stages.

the marginal zone, with an argillaceous or calcareous matrix containing only interstitial anhydrite with no gypsum. This zone can be very wide, ringing a small central playa lake, but in other cases it is restricted to the margins of a broad playa lake. This variation is dependent on the basinal water budget.

During the phases of maximum stability and brine evolution of the evaporitic system, glauberite and polyhalite deposits are also formed, as noted previously. These sulfates are described by Salvany and Ortí in this volume.

In summary, the pair of gypsum deposits, the Falces and Lerín units, represent a very long period of evaporitic conditions during the middle to late Oligocene and early Miocene in the Navarra Basin. Throughout this time span the sedimentologic characteristics of the central saline lakes and their saline mud flats remained virtually unaltered. The major evaporitic units represent stages of significant stabilization of the evaporitic environment. Here, the alluvial systems were confined to the basin borders and were represented in the central area only by thin argillaceous intercalations. In the gypsum units the lithofacies dominance was controlled by the position of the evaporitic lakes. Thus in the basin center laminated facies dominated (either gypsum and/or halite), but the same unit at the margin was almost exclusively made up by nodular anhydrite lithofacies. The shifting of the sedimentary trough was the result of basement fault movement which took place under the compressive regime during the Oligocene and continued into the early Miocene.

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