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Continental Evaporitic Sedimentation in the Ebro Basin During the Miocene

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As in other continental Tertiary basins of Spain, evaporitic sedimentation continued in the Ebro Basin during the Miocene. The distribution of Miocene deposits follows a similar pattern to those of the Paleogene (see figure 8.3, this volume). Many of these deposits have also been affected by synsedimentary diagenesis and modification. These changes are well developed and clearly documented. It is for this particular reason that we include the Miocene sediments in what is essentially a discussion of Paleogene sedimentation.

The Miocene evaporitic deposits are made up of sediments that formed within:

(a) small lacustrine systems adjacent to basin borders, in which the ionic concentration of the water is low;
(b) large central lake systems, in which the salinity reaches the chloride precipitation stage;
(c) continental sabkha zones which may be related to either of the other bodies of water (a) or (b).

The first group (a) includes the assemblage of small, basin-margin formations developed close to the Iberian Ridge border. These formations are present in the areas of Zaragoza, Navarra, and La Rioja provinces. Other evaporative areas include Borja, Ablitas-Monteagudo, Pozuelo, as well as minor deposits in such regions as Ribafrecha and Calanda, and are roughly time-equivalent. These deposits are characterized by the preservation of primary gypsum, which is of the microlenticular matrix-free type. In these deposits gypsum bioturbation is ubiquitous, nodular chert is common, and halite vestiges are absent. The bedding is thick and massive. Sedimentologically these deposits are equivalent to those of the Paleogene age that developed along the Catalánide border.

The second group (b) includes the extensive system of the Zaragoza Formation and its peripheral units in the central area of Aragón, and the Cerezo Gypsum in Burgos province. In both Aragón and Burgos the sequences are very thick and are dominated by the laminated-nodular facies association, which intercalates with sodium-calcium-sulfates in Cerezo and sodium-calcium-sulfates and halite in Zaragoza.

The third group (c) includes the deposits of the Mediana, Gelsa, and Azaila type, characterized by the development of extensive nodular anhydrite in a clayey or calcareous matrix. The laminated gypsum facies is almost entirely absent. In this grouping, the interstitial and displacive growth of early diagenetic anhydrite was the dominant formative process.

Central Evaporitic Systems of the Ebro Basin During the Early-Late Miocene

At the beginning of the Miocene the axis of maximum subsidence in the Ebro Basin shifted towards the south, trended NW-SE, and occupied approxi-

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mately the same position as does the present-day Ebro river. During the Oligocene to Miocene transition, a broad "pre-Aquitanian" unconformity developed throughout the western part of the basin. In this new arrangement, the single evaporitic depocenter of the Navarra zone (the Falces Gypsum and Lerín Gypsum) became differentiated into two subsident zones and evaporites collected within both, although not synchronously. Of the two zones, one was located to the west in the Burgos region (Cerezo Gypsum, upper (?) Miocene) and the other, more important, to the southeast in the central part of Aragón (Zaragoza Gypsum, lower Miocene). Thus the Oligocene evaporitic systems of Navarra continued throughout the Miocene within the central and western parts of the Ebro Basin (see figures 8.3 and 8.4, this volume).

ZARAGOZA GYPSUM FORMATION

The Zaragoza Gypsum Formation is present at outcrop over a nearly rectangular zone trending northwest-southeast (figure 15.1A). The evaporitic basin is about 80 km long and about 40 km wide (Quirantes 1969). Maximum thickness in outcrop reaches 100 meters. Exploratory boreholes (for oil and mining) have penetrated and drilled into several halite layers bearing sulfates about 800 m below the surface. Several rivers cut through the formation, resulting in impressive, almost vertical cliffs (Ebro, Gállego, Jalón, Huerva, etc.), and facilitate its study. The age of the Zaragoza Gypsum is somewhere between the base of the Miocene and the middle Aragonian (early Miocene).

Laterally, the Zaragoza Formation passes into other time-equivalent evaporitic sulfate units that may be clearly differentiated from the Zaragoza itself, such as the Borja-Pozuelo Gypsum to the west and the Vinaceite Gypsum to the south. A schematic representation of this transition is shown in figure 15.1B. This formation passes laterally to several siliciclastic deposits and into some minor calcareous units. Several general studies on the overall deposition of the Zaragoza Formation have been carried out (Quirantes 1969; Birnbaum 1976; Mandado 1987).

Within the Zaragoza Formation there are four main intercalated halitic bodies, in particular in the areas of Remolinos, Torres de Berrelén, and Zaragoza (Torrescusa and Klimowitz 1990). These halite deposits are largely composed of banded halite (figure 15.2), which exhibit primary salt textures (hopper and chevron structures) in which some nodular anhydrite is noted (Ortí and Pueyo 1977; Fernández-Nieto and Galan 1979; Ortí 1990b). The bromine content of the salt is commonly between 1 and 15 ppm, which clearly demonstrates its continental origin. These halite facies formed in a very shallow saline lake affected by weak dilution episodes, in which nodules of anhydrite grew within thin pelitic interlayers, or within the salt itself. A peripheral belt of nodular anhydrite, partly replacing the halite, surrounds the central salt body. Synsedimentary replacive processes did not significantly affect the salt towards the inner part of the lake, in which perfectly preserved depositional structures are present. However both early and late diagenetic dissolution phenomena can be observed locally in the mine galleries, especially in some areas where the banding has been destroyed and replaced by patches of transparent, inclusion-free, halite crystals (Ortí and Pueyo 1977). The clear halite crystals, of centimetric to metric size, display the lowest bromine content of any of the halite ("sal de compás").

A 106 m exploratory borehole drilled inside the gallery of the Remolinos mine cut salt layers with glauberite crystals and halite/anhydrite pseudomorphs after glauberite that extended for 80 m; glauberite continued to the bottom of the hole. The geochemical study of this salt (Garcîa Veigas 1993; Garcîa Veigas et al. 1994) reveals low bromine, magnesium, and potassium content. Fluid inclusion studies of the same salt also contain very low bromine, magnesium, and potassium—falling below the limit of detection. The SO_4^{-2} content is significant only in samples associated with glauberite beds. These data agree with the mineral paragenesis in the Zaragoza Gypsum Formation (gypsum/anhydrite, glauberite, thenardite, and halite), where no magnesium or potassium minerals are present. This is in strong contrast to the polyhalite bearing sodium sulfate deposits of Alcanadre (Lerín Gypsum Formation) (see chapter 14, this volume).

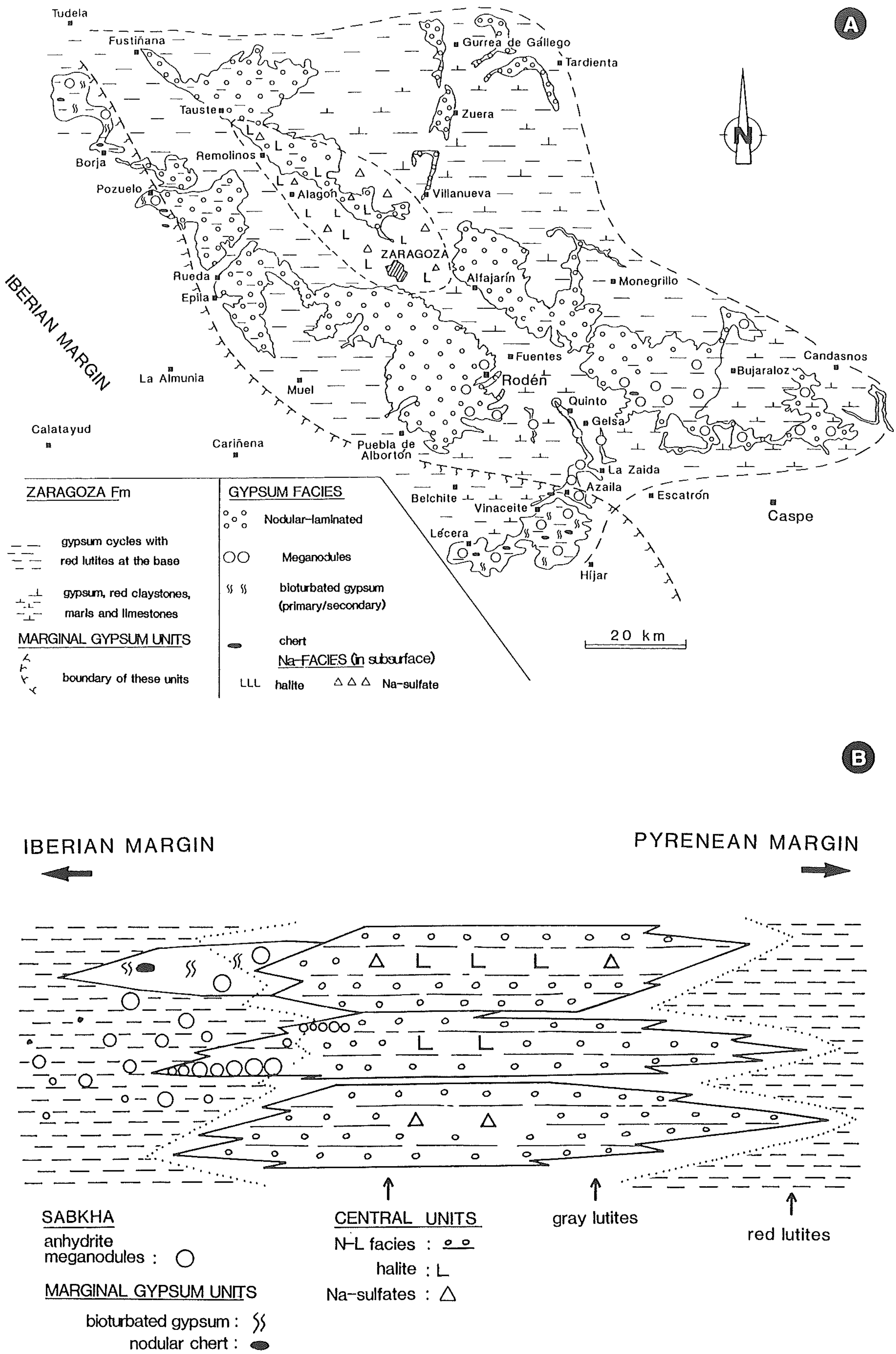

A
Tudela
Fustiñana
Gurrea de Gállego
Tardienta
Borja
Tauste
Zuera
Remolinos
Pozuelo
Alagón
Villanueva
ZARAGOZA
Alfajarín
Monegrillo
Rueda
Epila
IBERIAN MARGIN
Fuentes
Rodén
Candasnos
Bujaraloz
La Almunia
Muel
Quinto
Gelsa
Calatayud
Cariñena
Puebla de Alborton
La Zaida
Azaila
Belchite
Escatrón
Vinaceite
Caspe
Lécera
Híjar
20 km
ZARAGOZA Fm
gypsum cycles with red lutites at the base
gypsum, red claystones, marls and limestones
MARGINAL GYPSUM UNITS
boundary of these units
GYPSUM FACIES
Nodular-laminated
Meganodules
bioturbated gypsum (primary/secondary)
chert
Na-FACIES (in subsurface)
halite
Na-sulfate
B
IBERIAN MARGIN
PYRENEAN MARGIN
SABKHA
anhydrite meganodules :
MARGINAL GYPSUM UNITS
bioturbated gypsum :
nodular chert :
CENTRAL UNITS
N-L facies :
halite : L
Na-sulfates :
gray lutites
red lutites

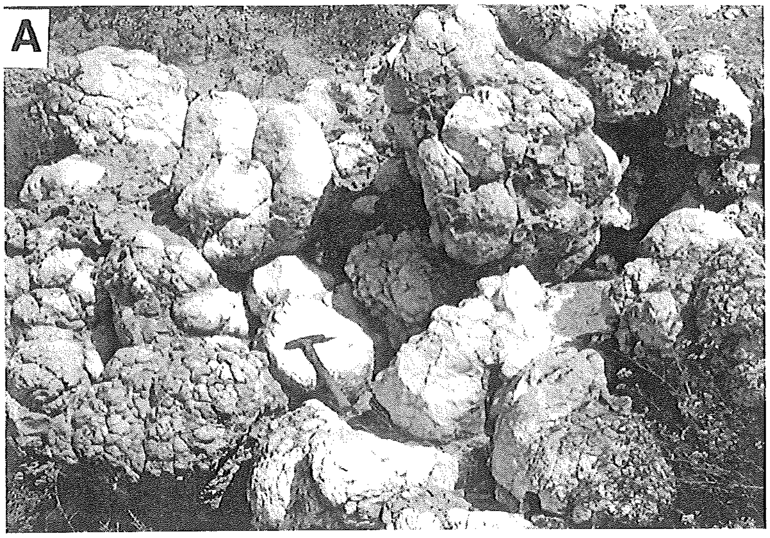
FIG. 15.1

FIG. 15.2. Bedding characteristic of the Zaragoza Halite. Decimetric-order banding of hopper chevron halite seen in the Mina Real of Remolinos (Zaragoza province).

Further from the basin center, a huge saline mud flat (sabkha) developed over an area of more than 50 km^2, in which nodular anhydrite (and probably also glauberite) of early diagenetic origin alternates with a laminated gypsum facies. The original laminated gypsum was completely transformed into anhydrite and glauberite during very early diagenesis. Today it crops out on the surface as secondary gypsum. As happens in the Lerín and Falces formations, borehole data show that metric-order glauberitic layers are also intercalated within the salt across a wide zone (in the area of Utrebo-Zaragoza and in Remolinos), thus demonstrating the same paragenetic assemblage. Mandado (1987) also cited the existence of some thenardite layers.

Units peripheral to the Zaragoza Formation such as the Vinaceite Gypsum (zone between Vinaceite and Azaila) are characterized by the presence of primary microlenticular gypsum (preserved), some large nodules of alabastrine secondary gypsum, and chert nodules. These evaporitic units constitute type (a) (small lacustrine systems). The thickness of the evaporites reaches up to 100 m in many outcrops. Other similar units are also developed regionally. Locally, in the transition between the (a) and (b) types, some sabkha-type units develop, as in the area near Rodén and Azaila, which is characterized by the presence of large alabastrine nodules within argillaceous beds of red clays (figure 15.3A and B) that are very actively being exploited.

FIG. 15.1. The Zaragoza Gypsum Formation. A. Lithologic map showing the facies distribution in the central part of the outcropping area of the Zaragoza Gypsum Formation. B. Cross-sectional scheme, not to scale, illustrating the lateral transitions between the central halite/glauberite/anhydrite units of the Zaragoza Gypsum Formation and the marginal gypsum units with lower concentration facies and chert (i.e., Pozuelo to Remolinos cross-section). The model also includes some sabkha occurrences with extensive development of meganodules of anhydrite (i.e., from Azaila to the north). (Taken from Ortí 1990b.)



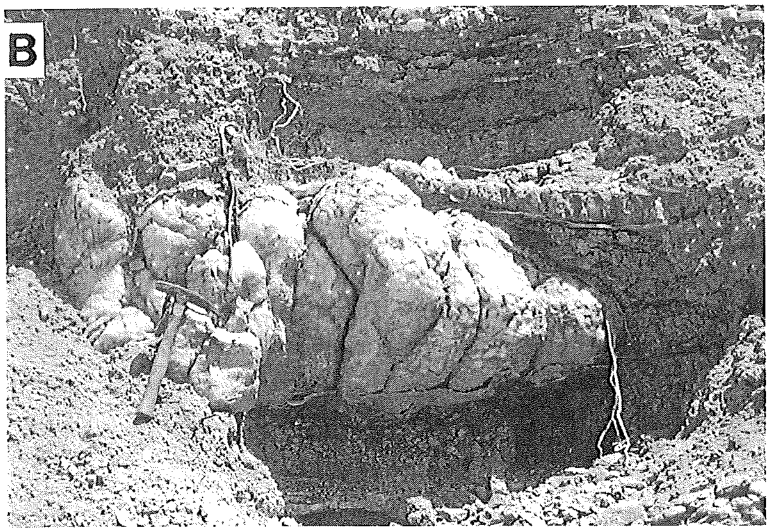


FIG. 15.3. Anhydrite meganodules of probable sabkha origin in the Miocene near Rodén, now preserved as alabastrine secondary gypsum. A. Spheroidal nodules. B. Vertically aligned elongate gypsum nodules that together form a lenticular mass. Hammer for scale in both photographs.

CEREZO GYPSUM UNIT

In the western border of the Ebro Basin there exists a narrow, tectonically-controlled zone (30 to 40 km wide) trending east-west, called the Bureba corridor, which is considered to have been the connection between the Ebro and the Duero basins. In this graben, subsidence during the Tertiary was locally as much as 5000 m. During the Miocene significant amounts of evaporitic sedimentation took place in the westernmost part of the Bureba area in what is called the Cerezo Gypsum Unit (see figures 8.3 and 8.4, this volume). The Cerezo Gypsum reaches an outcrop thickness of 150 m, but data about its continuity in the subsurface have not been published. Portero et al. (1979) assigned this evaporitic unit to the early Miocene, while Riba et al. (1983), Anadón (1990), and Riba and Jurado (1992) have argued that it is late Miocene. This unit passes laterally into detrital and calcareous facies and is not overlain by any younger deposits. The gypsum facies, which are mostly formed by secondary gypsum with only minor amounts of primary selenitic crystals at the top of the sequence, are defined by an alternation of

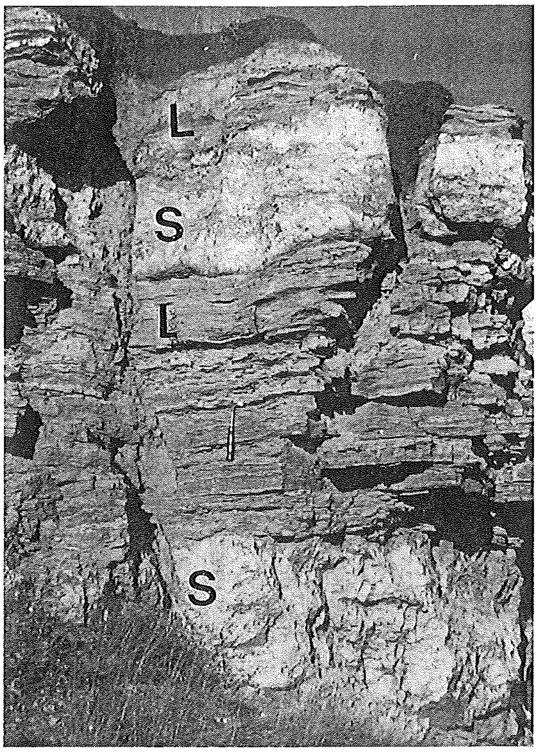


FIG. 15.4. Sabkha cycles in the Cerezo Gypsum Unit seen in the Villalómez quarries, Province of Burgos (1–5 m per cycle). In each cycle laminated gray lower horizon (L, lake stage) is overlain by an upper massive nodular layer (white alabastrine; S, sabkha stage). Almost all calcium sulfate now present is secondary gypsum (see hammer for scale).

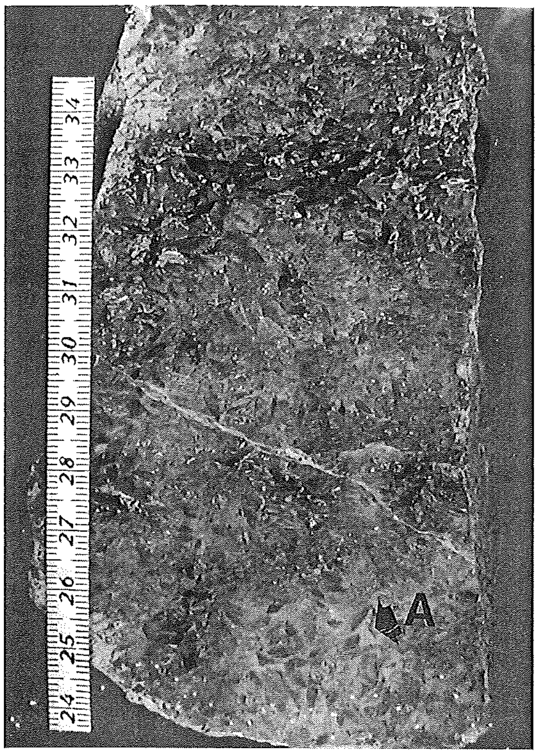


FIG. 15.5. Polished slab of the glauberite rock of Cerezo de Rio Tirón deposit. Note the presence of a fine-grained anhydritic matrix (A) between the coarse glauberite crystals.

laminar-nodular facies, which locally exhibit well-defined cyclic trends. Many of these depositional cycles in the marginal zone are of the sabkha type (figure 15.4). These facies are rather similar to those of the Zaragoza Formation (lower Miocene) and Lerín and Falces formations (Oligocene–lower Miocene of Navarra). The secondary gypsum comprising this formation ranges from alabastrine to megacrystalline and also contains typical features proving that a glauberite precursor was present.

The Cerezo Gypsum Unit contains intercalated glauberite layers that crop out in the Belorado—Cerezo de Rio Tirón area. Boreholes in that locality show an alternation of glauberite and anhydrite beds. At least six major layers of glauberite are known in the Cerezo, with individual thicknesses of several meters. Anhydrite is mainly composed of fine-grained nodular textures while glauberite is banded or massive, with a range in crystal size of millimeters to one centimeter (figure 15.5). More rarely, the glauberite displays fine-grained textures with nodular and enterolithic layering. Neither halite nor thenardite layers have been found: a complete investigation of the sequence from boreholes has never been published. The geology of this deposit in Cerezo was discussed by Menduiña et al. (1984). Two intensely exploited glauberite mines, in Belorado and Cerezo de Rio Tirón, are currently active.

Primary Gypsum Deposits of the Peripheral Systems: Ablitas Gypsum

Although it is a fairly thin deposit, the Ablitas-Monteagudo Gypsum Unit constitutes an interest-

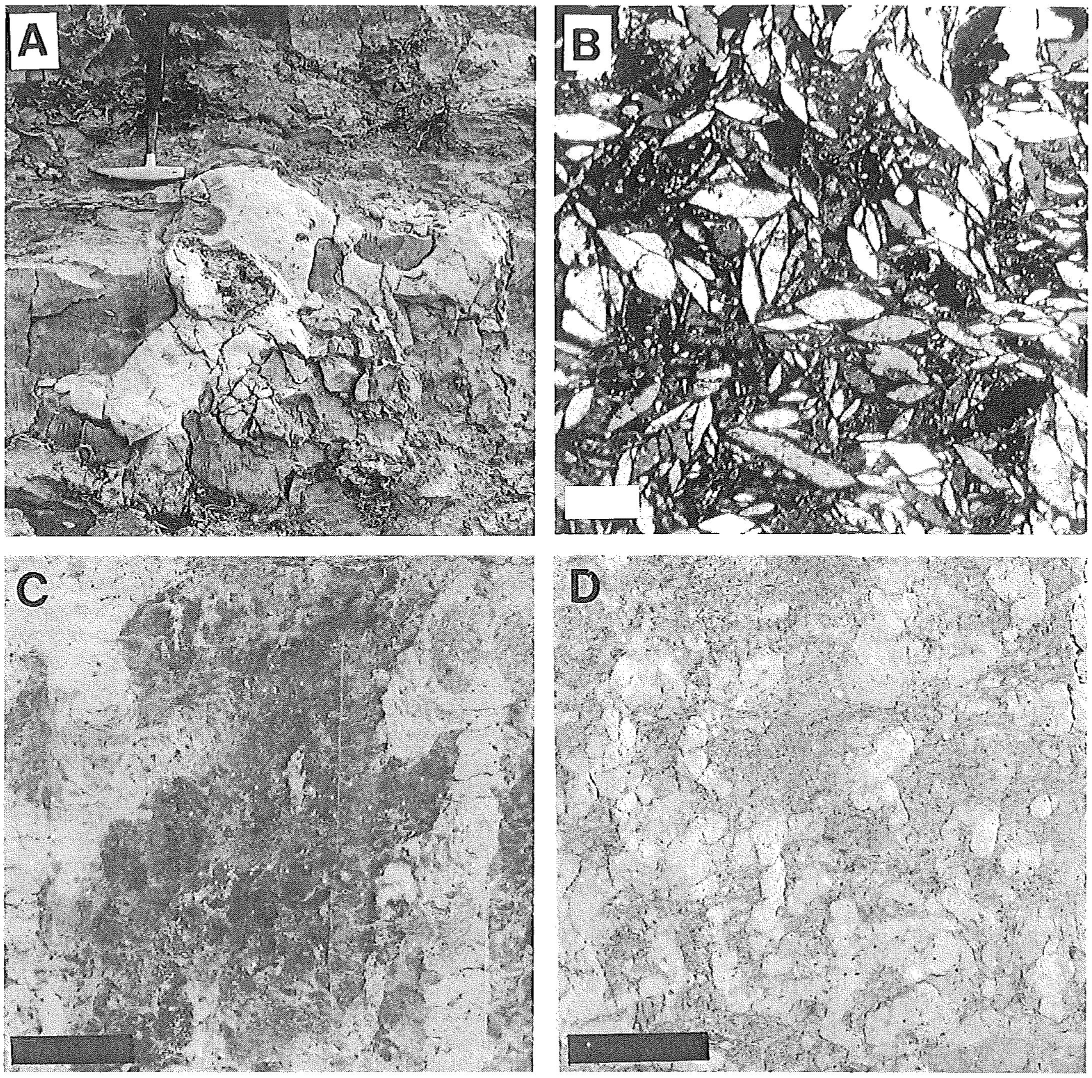


Fig. 15.6. Aspects of the Ablitas Gypsum, both primary and diagenetic features. A. Chert meganodule replacing the primary microlenticular gypsum in the Ablitas quarry. B. Photomicrograph of the microlenticular primary gypsum (scale bar, 100 microns). C and D. Two aspects of burrowing affecting the microlenticular primary gypsum (polished slab). Burrows are filled by gypsum and also by carbonate (scale bars, 1 cm).

ing evaporitic formation that displays very well- defined sedimentary and petrologic characteristics (similar to those described by Ortí in chapter 12 of this volume for the gypsum of the Cornudella Group) (Castiella et al. 1978; González and Galán 1984; Ortí and Salvany 1986a; Ortí et al. 1986a; Mandado 1987; Pérez et al. 1988; Salvany 1989; and Salvany et al. 1994b). This formation is composed of gypsum with associated carbonate, clay, and chert nodules (figure 15.6A–D). No vestiges of halite or sodium-sulfates are known. All these features are rather similar to those in the gypsum units present in the areas to the southeast, such as Borja, Pozuelo de Aragón, Vinaceite, Calanda, and to the west at Autol and Ribafrecha (figure 15.7; and see figures 8.3 and 8.4, this volume).

Gypsum is mainly alabastrine (secondary), but towards the western part of the formation it progressively changes to the microlenticular primary facies. The alabastrine secondary gypsum displays

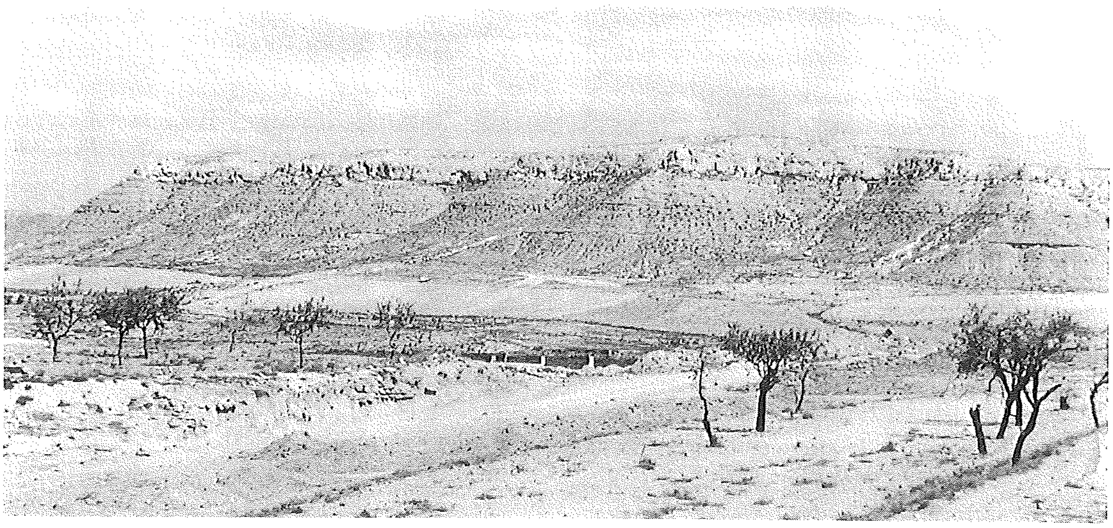


Fig. 15.7. View of Ablitas Gypsum Unit near the village of Ablitas. Gypsum layers form the top of the tabular relief and are intercalated within the lutites of the Alfaro Formation.

Fig. 15.8. Meganodule of secondary gypsum replacing the microlenticular primary gypsum as seen in the Ablitas quarries. The nodule, displaying a thick envelope of satin spar gypsum veins (at arrow), is formed by a single crystal of secondary gypsum (megacrystalline variety) showing cleavage surfaces. This replacement does not result in deformation of enclosing sediment but is clearly cross-cutting.

nodular lithofacies of two major types: (a) nodules and meganodules (large white alabastrine nodules) of very pure calcium-sulfate varying between 20 cm and 1 to 2 m in diameter, and (b) micronodules, in general having a greenish tint and variable sizes (between less than 1 cm and 2 to 4 cm). Meganodules may occur as individuals or be arranged in layers. In the first case they are commonly surrounded either by micronodules, or by microlenticular primary gypsum, which they replace (figure 15.8).

The primary gypsum forms beds with a thickness of about 1 meter made up of two major lithofacies:

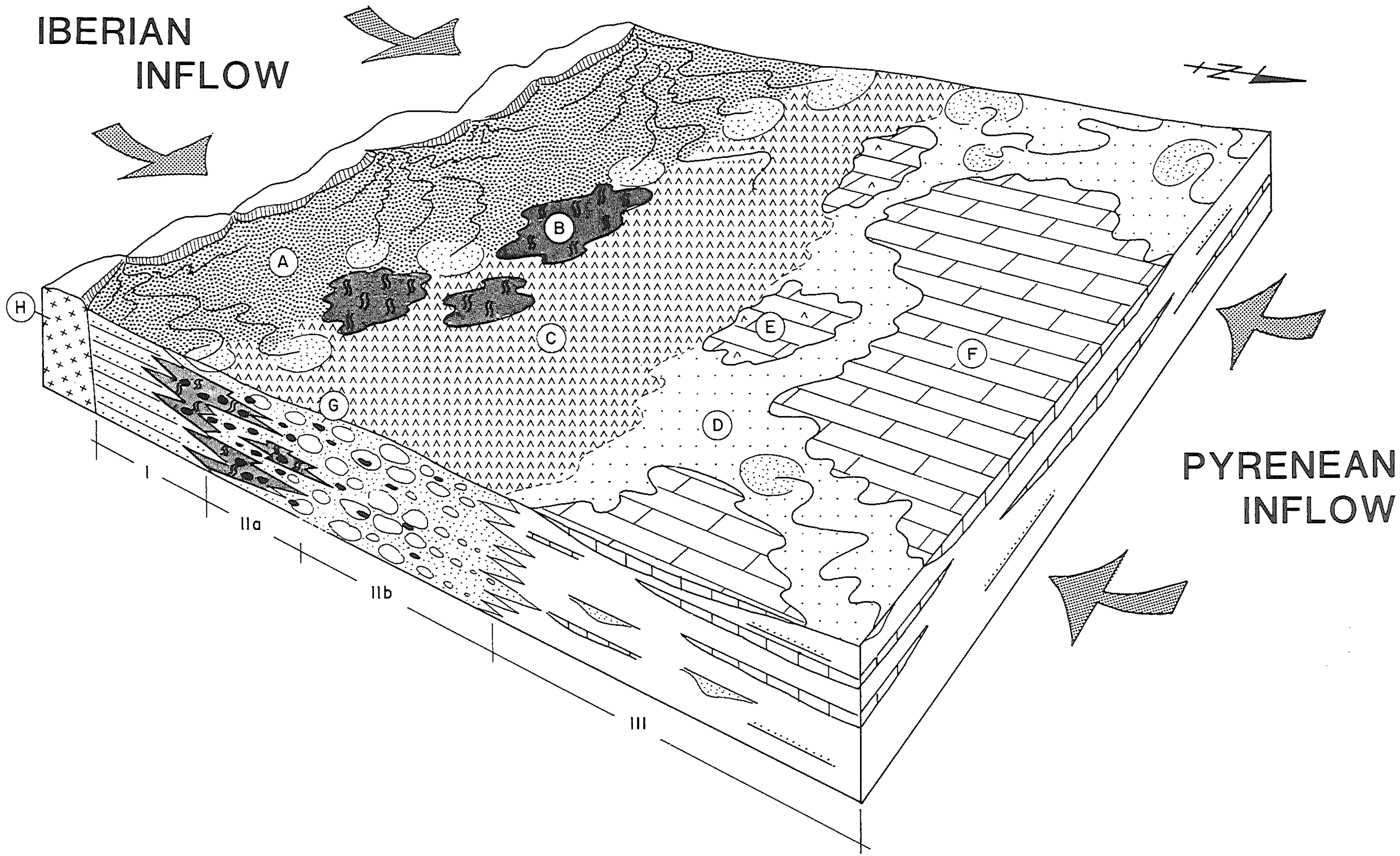


Fig. 15.9. Three-dimensional diagram of the Monteagudo-Ablitas Gypsum Unit showing the distribution of the detrital (I), evaporitic (II a and b), and carbonate (III) facies; drawn from the southern border of the basin (Iberian Range) towards the center. Key: A = alluvial fans with conglomerates, sandstones, and clays; B = a peripheral gypsiferous shallow lake displaying bioturbation and chert nodules (black); C = zone of anhydritization containing meganodules of both anhydrite (white) and chert; D = distal lutitic plain with carbonates and sandstones; E = shallow calcareous lake with gypsum intercalations (rosettes); F = shallow calcareous lake with well-developed bioturbation; G = chert nodules; H = Paleozoic-Mesozoic basement (Iberian Range) (taken from Salvany 1989).

(a) fine-grained (100 to 500 microns), brownish gypsum with a massive appearance, composed of tiny crystals with a microlenticular habit. This lithofacies may contain an abundant matrix of irregularly distributed carbonate, and is probably the result of primary, very shallow subaquatic precipitation.

(b) medium-grained (<1 mm to 2–3 cm), greenish gypsum, with crystals having a spatulate-lenticular twinned habit.

Both lithofacies are intensively burrowed (figure 15.6C and D). Burrows are usually filled with gypsum of the same type, but sometimes also with carbonate and chert.

The micronodular secondary gypsum apparently results from the early diagenetic transformation of primary gypsum into anhydrite, caused by water level fluctuations in the formative sulfatic lake. Meganodules apparently originate in a more advanced stage of diagenesis, perhaps due to groundwater circulation of concentrated solutions (Salvany et al. 1994).

In this sequence, the carbonate mineral is calcite, with minor amounts of dolomite. Texturally it is a mudstone to wackestone with abundant bioclasts of charophytes, ostracods, and gastropods. The clays are mainly illite and chlorite, but smectites and minor amounts of kaolinite are also present. In this formation magnesian smectites and sepiolite are also known (González and Galán 1984). Chert nodules are well developed in the various types of gypsum, although they occur preferentially in the primary gypsum. Meganodules of chert (>50 cm in diameter) are common. Both gypsum and carbonate are replaced by the chert. Because of the position of these evaporites within the detrital host argillaceous formations, and the central distribution of the gypsum facies within the formation, the Ablitas-Monteagudo Gypsum may be interpreted as having formed within a playa lake setting adjacent to the toe of the alluvial fans along the southern border of the Ebro Basin. Such fans grade to the north into a broad lutitic plain in which fluvial and calcareous lacustrine facies developed. During the early Miocene, clastic sediments having a Pyrenean provenance were most common in this part of the Ebro Basin, while those with a detrital composition having an Iberian range provenance were restricted to a narrow southern belt. In the transition zone between the two sedimentary systems, deposition of evaporites of the Ablitas Gypsum took place (figure 15.9).

In several areas near the southern border of the basin, other restricted Miocene evaporite formations with similar petrologic and sedimentologic characteristics to those of the Ablitas-Monteagudo Gypsum developed (see figures 8.3 and 8.4, this volume). These include, among others, the Borja Gypsum and the Pozuelo de Aragón Gypsum in the province of Zaragoza, which are closely related to the Ablitas Unit, and the Autol Gypsum. However, the latter is older and has been completely altered into secondary gypsum. Finally, the Ribafrecha Gypsum, close to Logroño, is a formation in structural contact with the Triassic evaporites of the Iberian Range border. The sediments display a playa lake character, with a clear overprint by the nodular facies (meganodules) that developed by replacement under a ground water regime. Nodular chert is present and some primary gypsum is preserved.

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