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La Mancha Triassic and Lower Lias Stratigraphy, a well log interpretation

Estratigrafía del Triásico y Lías Inferior en el área de La Mancha, una interpretación de registros de sondeo

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Abstract

The Stratigraphy of the Triassic Keuper and the lowermost Liassic sedimentary interval has historically attracted much less attention than the adjacent sediments of Muschelkalk and Buntsandstein, and Lower to Middle Lias. A twelve wells correlation, along a cross-section of the La Mancha area, has been prepared to demonstrate the arrangement of facies in these formations, as well as their respective ordering in sedimentary sequences. Well data show the existence of complex multistage thick evaporitic sequences in the lower and more saline K1 unit, and in the upper and relatively more anhydritic K4-K5 units. A clastic episode, K2-K3 units, extends across the zone with several sand rich fairways. The topmost Keuper K6 unit is a very good marker. Sedimentation continued upwards, lowermost Lias, with a thick evaporitic section, the Anhydrite Zone, which has a significant halite episode in the central part of the cross-section. It is remarkable the good correlation existing between outcrops and well data, for these formations.

Keywords: Triassic, Lias, La Mancha, Well Data, Evaporitic sequences

Resumen

La estratigrafía del intervalo sedimentario correspondiente al Keuper, Triásico, y al Lías basal ha atraído históricamente mucho menos interés que los sedimentos adyacentes del Muschelkalk y Buntsandstein, y del Lías Inferior y Medio. Se ha confeccionado una correlación de 12 sondeos profundos del área de La Mancha para mostrar la distribución de facies de estas formaciones, así como su ordenación en secuencias sedimentarias. Los datos de pozo muestran la existencia de secuencias evaporíticas complejas y multiepisódicas en la unidad inferior K1, de carácter más salino, y en la unidad superior K4-K5, relativamente más anhidrítica. El episodio clástico correspondiente a las unidades K2-K3 está extendido en toda la zona, con varias áreas preferenciales de acumulación de arenas. La unidad K6, la más alta del Keuper, constituye un excelente nivel guía. La sedimentación continúa en el Lías basal con otra potente unidad evaporítica, la Zona de Anhidrita, que muestra un episodio salino muy significativo en la parte central de la correlación. Es de resaltar la buena correlación que existe entre los afloramientos y las sondeos para estas formaciones.

Palabras clave: Triásico, Lías, La Mancha, datos de sondeo, secuencias evaporíticas

1. Introduction

The here called La Mancha Area is a geographic zone mainly covered by Tertiary sediments, located across several Mesozoic and Tertiary Basins, referred to as Madrid, Tajo, Cuenca, Iberian Range, Tabular Cover Area, and External Prebetic. This zone was subject to oil exploration efforts during the late 60´s and early 70´s by different Oil Companies; it could be considered the main active period, although there were a few earlier attempts. Later in the 80´s was again subject to a new phase of efforts. So far, this area has yielded no positive results.

The Triassic succession, object of this study, is the typical Germanic trilogy, Buntsandstein, Muschelkalk and Keuper, underlying a Lower Liassic evaporitic-carbonate section. Excellent summaries have been recently published in Gibbons and Moreno (2002), and Vera (2004). Historically a lot of effort has been devoted to the study of the Buntsandstein and Muschelkalk, from one side, and the Middle-Upper Lias, but the sediments of the Keuper and the lowermost Lias have received much less attention. Some key papers for these sections are Ortí (1974), Pérez-López *et al* (1994), Gómez and Goy (1997), Arche *et al.* (2002) and Arnal *et al.* (2002).

A NW-SE well correlation running from El Gredal-1, in the Almazán Basin, to Jaraco-1, in the External Prebetic, illustrates the stratigraphy of the area (Figs. 1 and 2). Most of the wells used in this correlation cut trough the lowermost Jurassic section and reached Basement or Buntsandstein at least, thus providing enough data to analyse these sediments (Fig. 2). Previous partial versions of this correlation are in Bartrina *et al.* (1990) and Castillo-Herrador (1974).

Well log suites are usually acceptable in quality and quantity, except for several wells that due to operational problems, mainly related to drilling across massive evaporitic sections, could not be properly logged, (i.e., Torralba-1, Belmontejo-1A or Gabaldón-1). In other cases the saline section was not properly anticipated and salt was not actually recovered and described until several hundreds of metres below its stratigraphic top, generating huge cavings, that affect log quantitative interpretation, but in many cases salt presence was inferred from drilling rates.

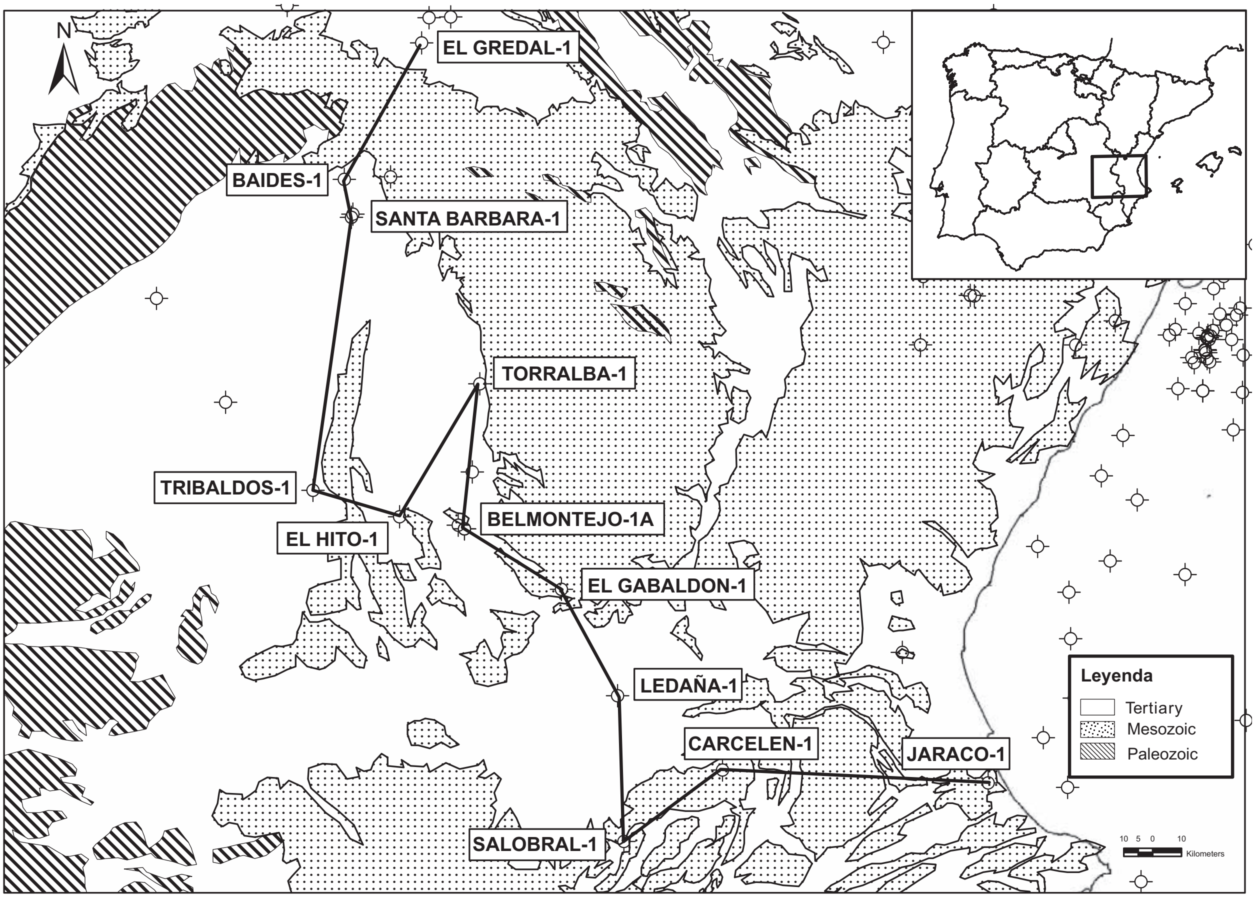

Fig. 1.- Location map.
Fig. 1.- Mapa de localización.

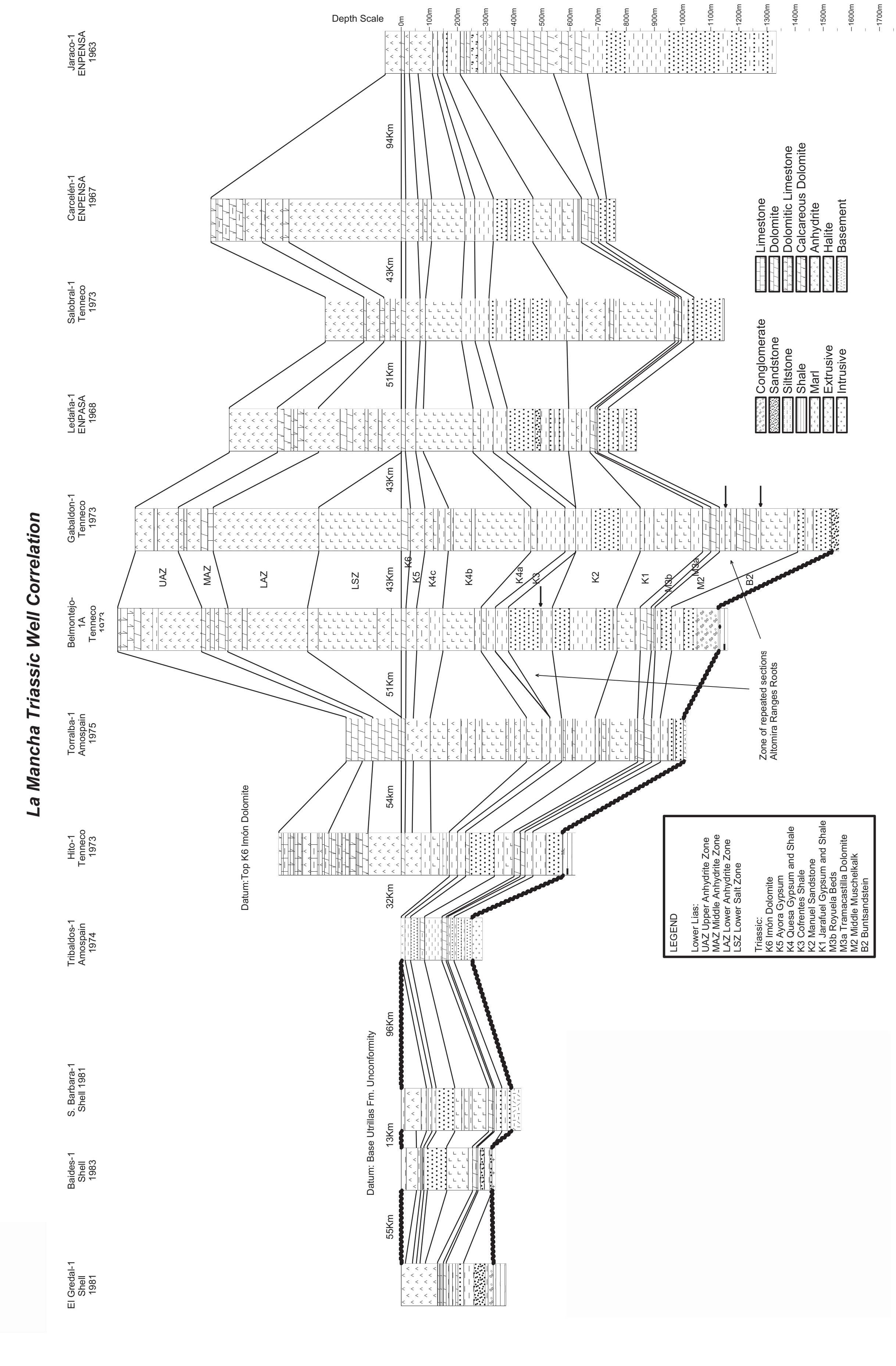

Fig. 2.- La Mancha Triassic-Lias Well Correlation
Fig. 2.- Correlación de sondeos, Triásico-Lías de La Mancha

2. Methodology

Well logs were subject to the standard process of digitizing, depth matching, splicing, and with the addition of lithological description from ditch cuttings, a set of composite logs were prepared for key sections. Most of the wells so have a standard suite of Gamma Ray, Resistivity, and Sonic logs, and some have Neutron and Density additionally. Depth matching and splicing are sometimes not satisfactory as logging suites were partial or as they were acquired sequentially, thus some logs still need to be slightly corrected. To complete well information, several cores were taken in most of the units, specially covering Anhydrite Zone, K5, K2, Muschelkalk and Buntsandstein; additionally, sidewall cores were collected in the most recent wells. After integrating all data available, a correlation for the 12 wells was prepared, for the units discussed below.

Besides, they were compared to the units already defined on the outcrops from the Iberian Range, Tabular Cover and Prebetic. Comparison with the formations defined in outcrops is very acceptable except for three main points: first, several formations show on outcrops a very thin bedded nature that can not be reproduced on the logs, 5-15 cm on outcrop versus 60-90cm on logs, thus leading to over-interpretation or over-simplification on the well log interpretation. Second, many wells show several thick saline levels, which usually have no correspondence in outcrop equivalents due to dissolution, so we have to bear in mind that while comparing these units (mainly K1, K4 and Anhydrite Zone) outcrops will show mostly the less soluble residue, thus introducing some uncertainty in their definition and interpretation. Third, there is a jungle of names to label these units, so in this paper we have tried to simplify this point, and we accept that some of the outcrop formations can be missing.

According to this correlation, the wells can be classified in three main groups, based on stratigraphic differences: the northern group, with a reduced Triassic section (both stratigraphically and eroded), unconformably overlain by the Cretaceous Utrillas Fm. (El Gredal-1 to Tribaldos-1), the central group, with thick Keuper and Anhydrite Zone sections, overlain by the Lower Jurassic Cuevas Labradas Fm. (El Hito-1 to Carcelén-1), and the eastern group, which has substantial differences in the Triassic: thick Buntsandstein and Muschelkalk sections, and by contrast, a thin Keuper and Anhydrite Zone (Jaraco-1), (Fig. 2).

3. Well Data Interpretation

The Buntsandstein (B2), (Figs.3-4), is quite uniform over the area, except for Jaraco-1, with thickness varying from 50 to 150m, and a tendency to thin towards the Hesperian Massif can be observed (Baides-1 and S. Bárbara-1). Usually descriptions are sandstones, red to white, fine to coarse, feldespatic, ranging even to conglomerates in few cases, mainly at the base, alternating with minor shales and siltstones. In the wells showing conglomerates, a separate unit (B1) has been added, i.e. Belmontejo-1A. The presence of B2 unit in the wells, which did not reach Basement, Ledaña-1, Carcelén-1, the closest ones to the Iberian Ranges, is based on partial penetration and seismic evidence. The internal setup is grossly fining upwards sequences, and most of the wells can record two to three sequences.

On top of it, there is a very radioactive section (Fig. 4) interpreted earlier as Buntsandstein because of its lithology. Thickness varies from 20 to 60m. A more detailed interpretation has shown that the presence of dolomite and anhydrite, described in cuttings and previously discarded as cavings, has to be considered as native, as shown by cased wells at base Muschelkalk, side-wall core samples and higher sonic velocities and densities than suitable for sandstone. Shales, sandstones and few levels of anhydrite and dolomites, compose this section, usually of reddish colours, besides minor grey and green. This unit lies always conformable below the Muschelkalk, so we consider it as Middle Muschelkalk (M2), and has been dated as Ladinian in Baides-1; it should be equivalent to El Mas and Torete Fms., (López-Gómez, 1987; Pérez-Arlucea, 1987), or the Middle Muschelkalk (M-2) of the Catalan Ranges (Virgili, 1958).

The Muschelkalk (Figs. 4-5) is mainly composed of dolomites, grey to tan, massive at the base (M3a), and argillaceous, or interbedded with shales (M3b), towards the top. Thickness ranges from 40 to 15m, and 30m to 5m respectively, as we move west or south (El Gredal-1, Baides-1, and Salobral-1). Several maximum-flooding surfaces can be interpreted from the logs (Martínez del Olmo, 1996); the lowermost section will be accordingly the transgressive system tract, while the upper one corresponds to the highstand system tract. Several radioactive and/or very hard peaks could be correlated to the outcrop described hard grounds and ferruginous surfaces. We correlate them to the Tramacastilla Dolomite and the Royuela Beds respectively (Pérez-Arlucea and Sopeña, 1985). The upper contact with the Keuper, K1, shows sharp and clean contrast.

The Keuper shows, except in El Gredal-1, a good correlation with the units defined by Ortí (1974).

K1 unit, Jarafuel shale and gypsum, shows a thick evaporitic section, mainly halite, clear, white, or pink, alternating with dark shales, and anhydrites, and few levels of dolomite (Figs. 5, 6). Thickness for this K1 unit ranges

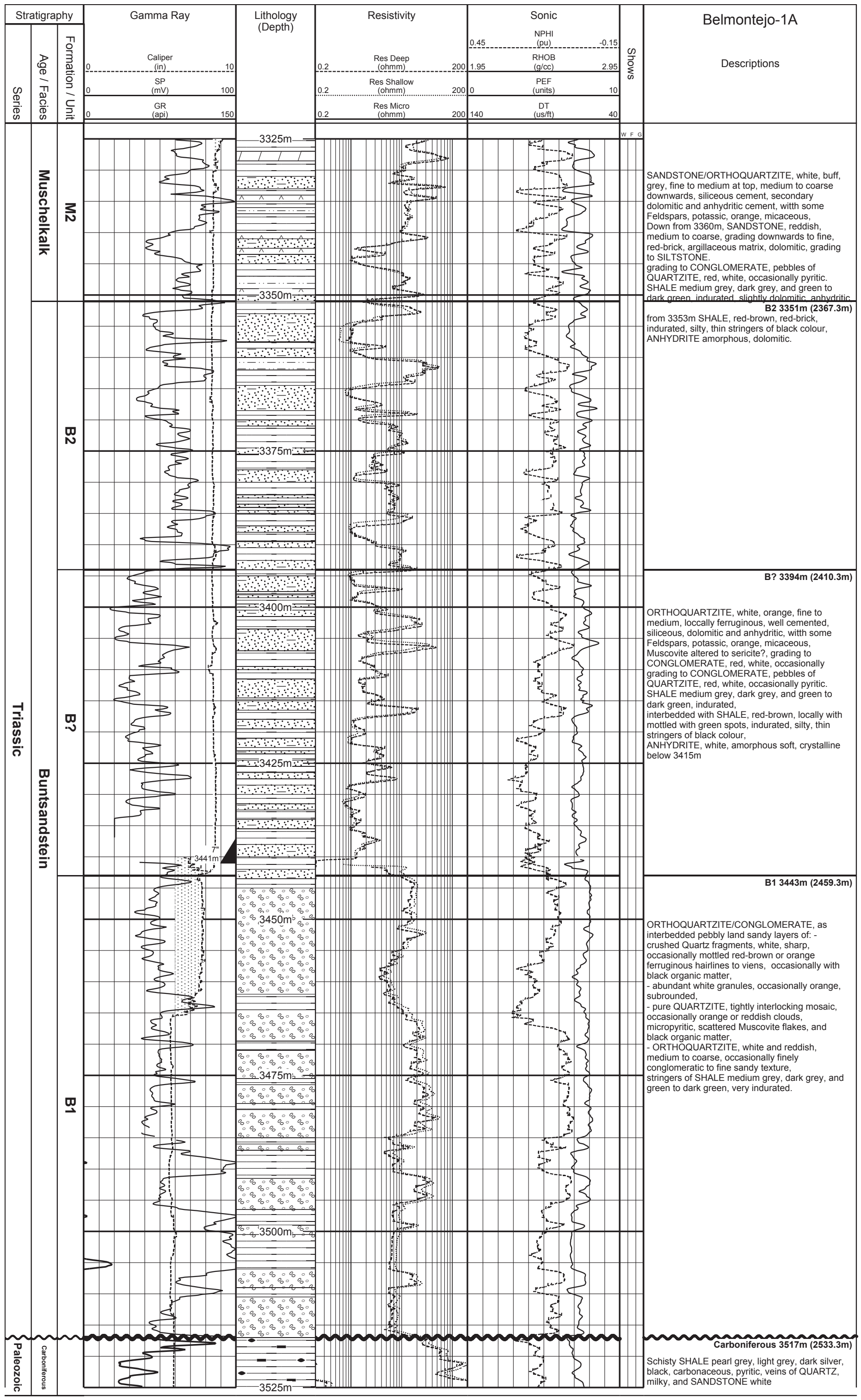

Fig. 3.- Belmontejo-1A composite log, B1, B2 sections

Fig. 3.- Belmontejo-1A log compuesto, intervalos B1, B2

from 40m to 380m. Easy to recognize by their velocities, in some wells even sylvite has been described, although has no match to the gamma ray log readings. They are arranged in elementary evaporitic sequences (Suarez *et al.,* 1985), "evaporating upwards", composed by shales, dolomite, anhydrite and halite. Three main evaporitic cycles has been recognized, and, at least, 17 correlatable halite levels have been identified in most of the wells, from Santa Bárbara-1 to Carcelén-1, a lowermost fourth cycle only appears to be present in two wells, Carcelén-1 and Salobral-1, at the base of the K1 unit. Halite thins out or even disappears in the wells to the SW (Tribaldos-1).

K2 unit, Manuel sandstone, is mainly a clastic section (Fig. 7) with sandstones, described as white, grey, green

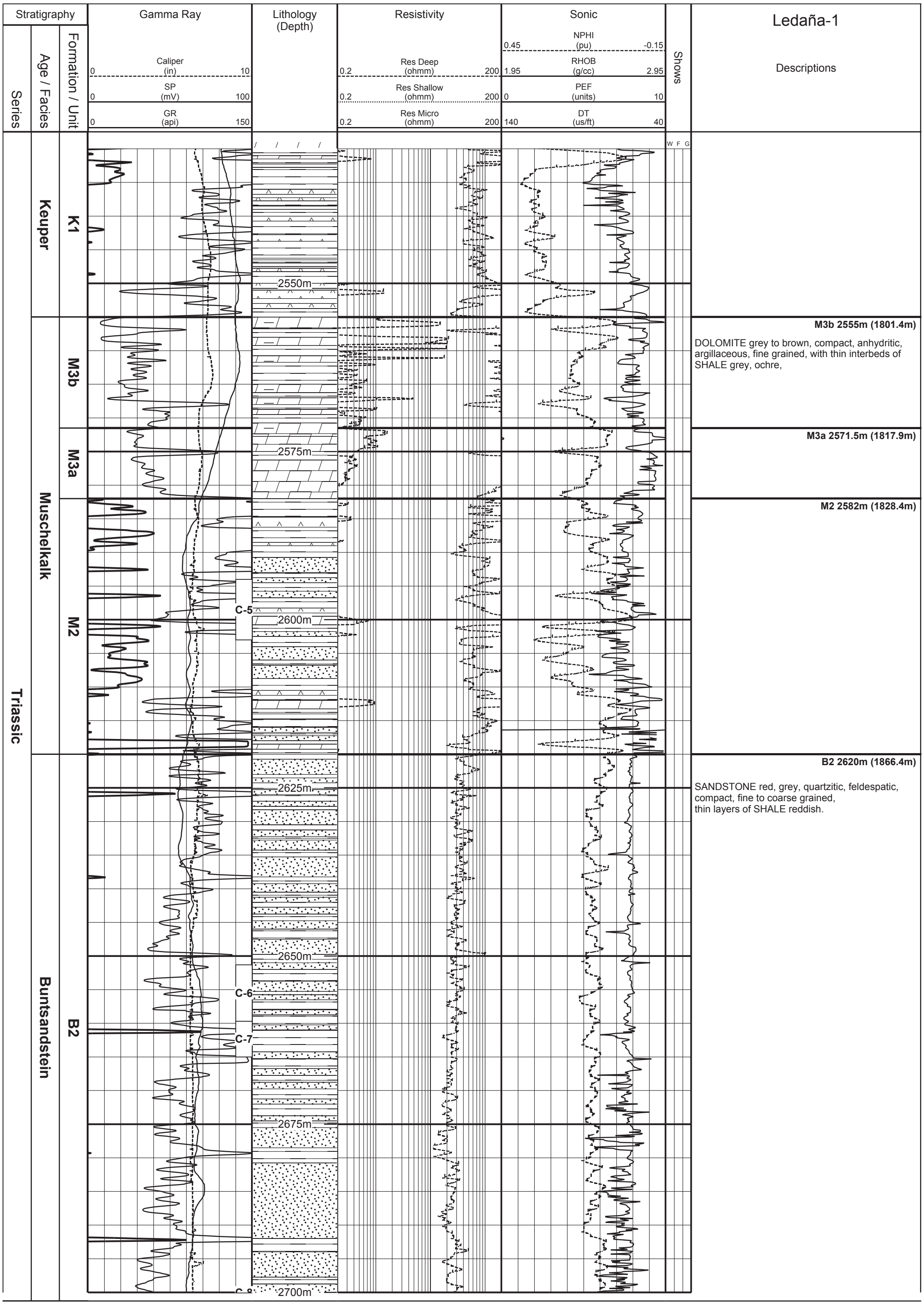

Fig. 4.- Ledaña-1 composite log, M2, M3 sections

Fig. 4.- Ledaña-1 log compuesto, intervalos M2, M3

and reddish, fine to very fine, well sorted and rounded, arranged in thin beds, less than 0.5-1m, except for several thick bodies, 5-10m (even reaching 20m in Ledaña-1), alternating with shales, anhydrites and dolomites. In some wells, a plant debris rich interval, described as lignitic remains, can be identified; in outcrops there is an equivalent level with abundant remains of Equisetal plants, according to our field observations, i.e. Alpera-Montealegre field section. Gross thickness for this interval varies from 50-70m in the northern wells, to 200-280m in the central wells. Interestingly enough are the thinner and scarce sand bodies in this interval found in Torralba-1 (Fig. 8), the closest well to the Iberian Range.

Worth to mention is the fact that some authors (Martínez del Olmo, 1996; Pérez-Valera and Pérez-López, 2003) have described sandstones bearing K1 Fm. This interpre-

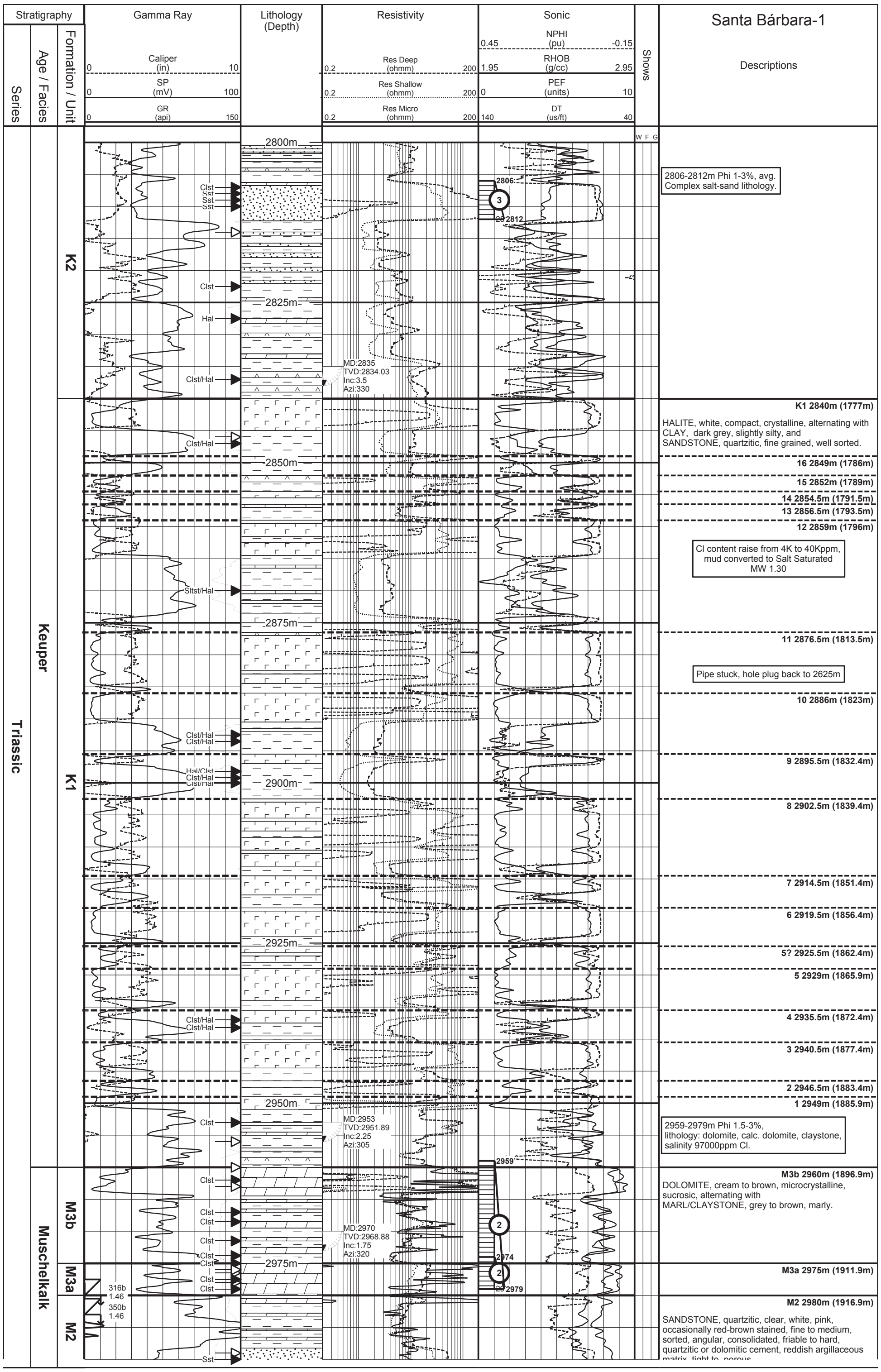

Fig. 5.- Santa Bárbara-1 composite log, M3, K1, K2 sections

Fig. 5.- Santa Bárbara-1 log compuesto, intervalos M3, K1, K2

tation is not supported by well results, where the contact between K1 and K2 is quite sharp. There are some well (or outcrop) sections where, in absence of sandstone levels, shale with dolomite and anhydrite levels are dominant and could lead to misinterpretations, but all these sections are inside of K2 unit. The base of K2 should not be interpreted at the base of the thick sandstones, mainly located to the middle to upper section of the unit; moreover in many cases its base is located even up to 100m below the massive sandstone levels. Outcrop examples show the same arrangement, i.e. Alpera-Montealegre field section, where the base of K2 unit is well below the massive sand rich levels. This interpretation is more consistent with the original K2 definition, Ortí (1974).

K3 unit, Cofrentes shale, consists of a very uniform brick red shale interval with thin green to blue levels of waxy texture, about 50m thick (Fig. 9). Remarkable is the presence of several persistent thin carbonate levels (0.3-0.5m), mostly dolomitic.

K4 unit, Quesa gypsiferous shale, is again a thick evaporitic interval (Figs. 10-11), which is in contrast with K1 in containing more anhydrite, and is usually reddish in colour. Thickness ranges from 40 to 550m, and is partly eroded in the northern wells, underneath the Cretaceous Utrillas Fm. Described as shale, mainly red, but green and grey too, with levels of anhydrite, white to grey, reddish, well layered or nodular, and halite, white to pink, and frequent bipyramidal quartz crystals, jacintos

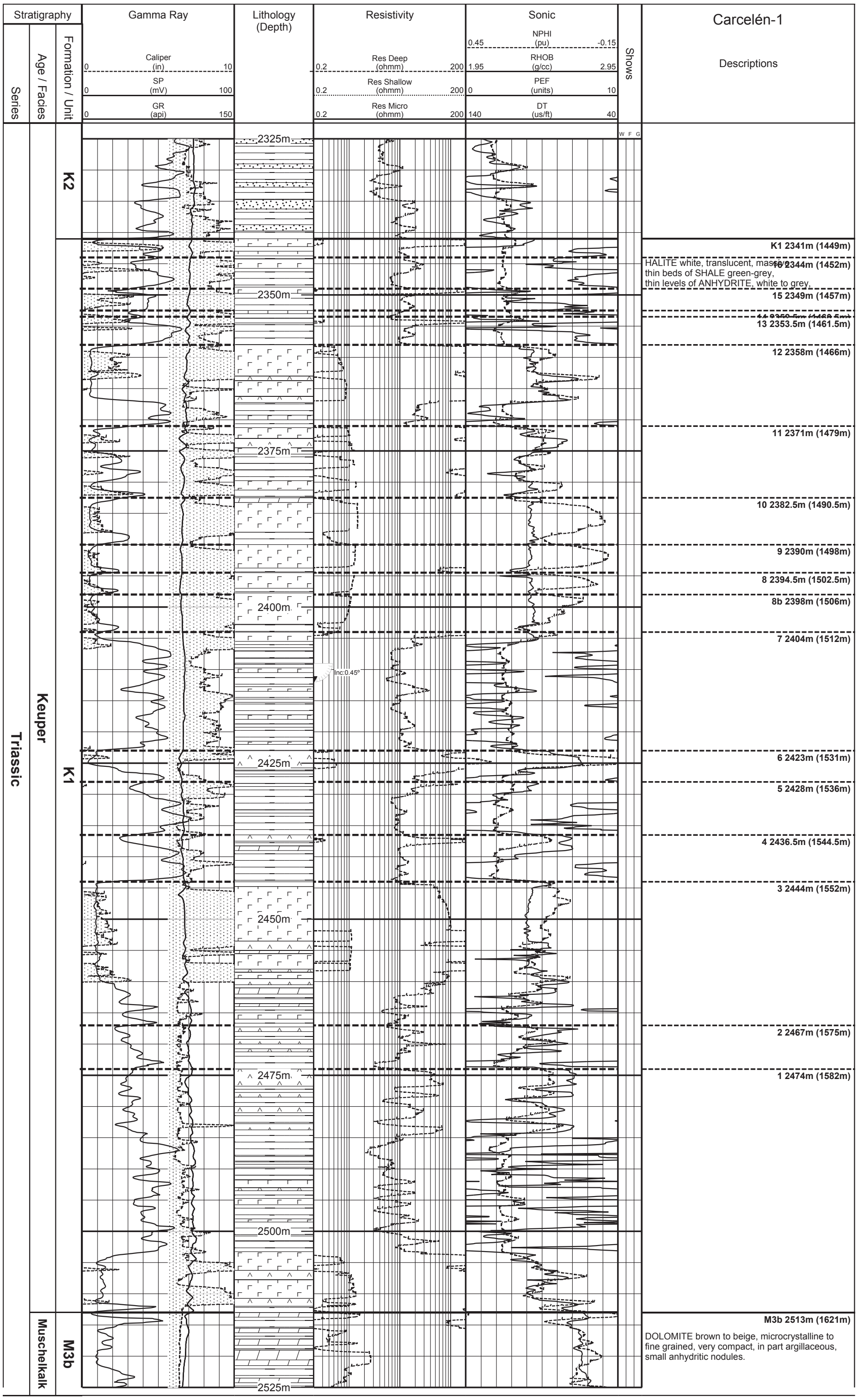

Fig. 6.- Carcelén-1 composite log, K1 section

Fig. 6.- Carcelén-1 log compuesto, intervalo K1

de Compostela. Three main complex evaporitic intervals has been defined, K4a to K4c (Suarez *et al*., 1985). The lower one, K4a, is very shaly, K4b is mainly halite, and K4c is mostly anhydritic, with halite only as thin beds. In the K4b, the sequences are arranged also in typical "evaporating upwards" successions, composed of shales, and halite, with dolomite and anhydrite layers subordinated or absent. Seven correlatable salt levels have been identified in most of the central group wells (El Hito-1 to Carcelén-1). On the contrary, K4c although formed by evaporitic sequences, "evaporating upwards" type, is almost devoid of halite and mostly formed by anhydrite, with thin levels of shale and dolomite.

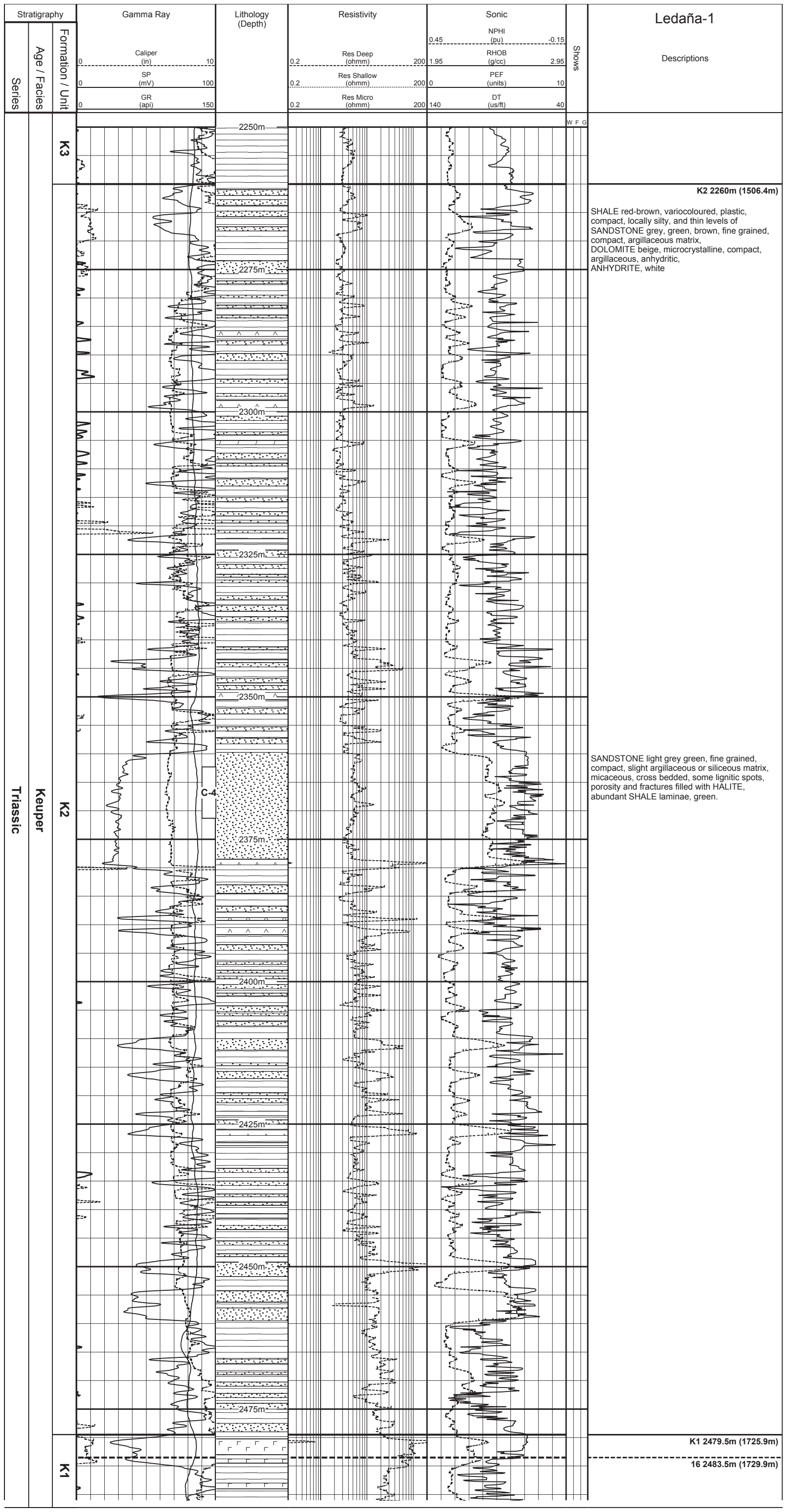

Fig. 7.- Ledaña-1 composite log, K2 section

Fig. 7.- Ledaña-1 log compuesto, intervalo K2

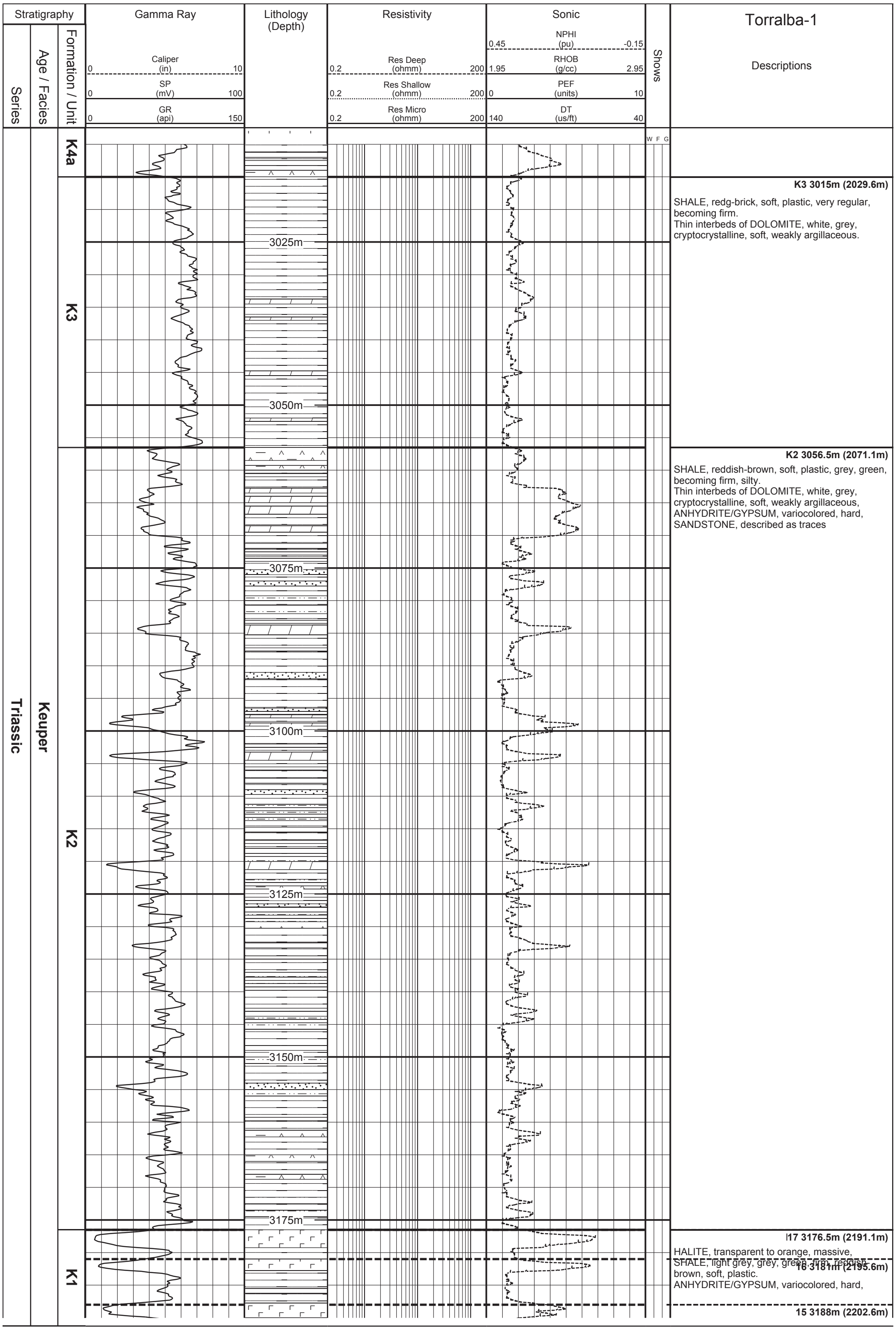

Fig. 8.- Torralba-1 composite log, K2 section

Fig. 8.- Torralba-1 log compuesto, intervalo K2

K5 unit, Ayora gypsum, is a well-bedded anhydritic interval, interbedded with minor levels of dolomites, usually greyish to whitish (Fig. 11). Thickness is about 50m. This unit clearly is more homogeneous than the precedent K4b and can be easily differentiated, both on well logs and outcrop.

The K6 unit, Imón/Zamoranos dolomite, overlying K5 (Goy *et al*., 1974; Pérez-López *et al*., 1992), is a thin but well developed dolomite level, 15 to 30m thick and constitutes an excellent marker as correlation datum (Figs. 11-14). The identification of this level is the key to separate the Liassic evaporites (Anhydrite Zone) from the

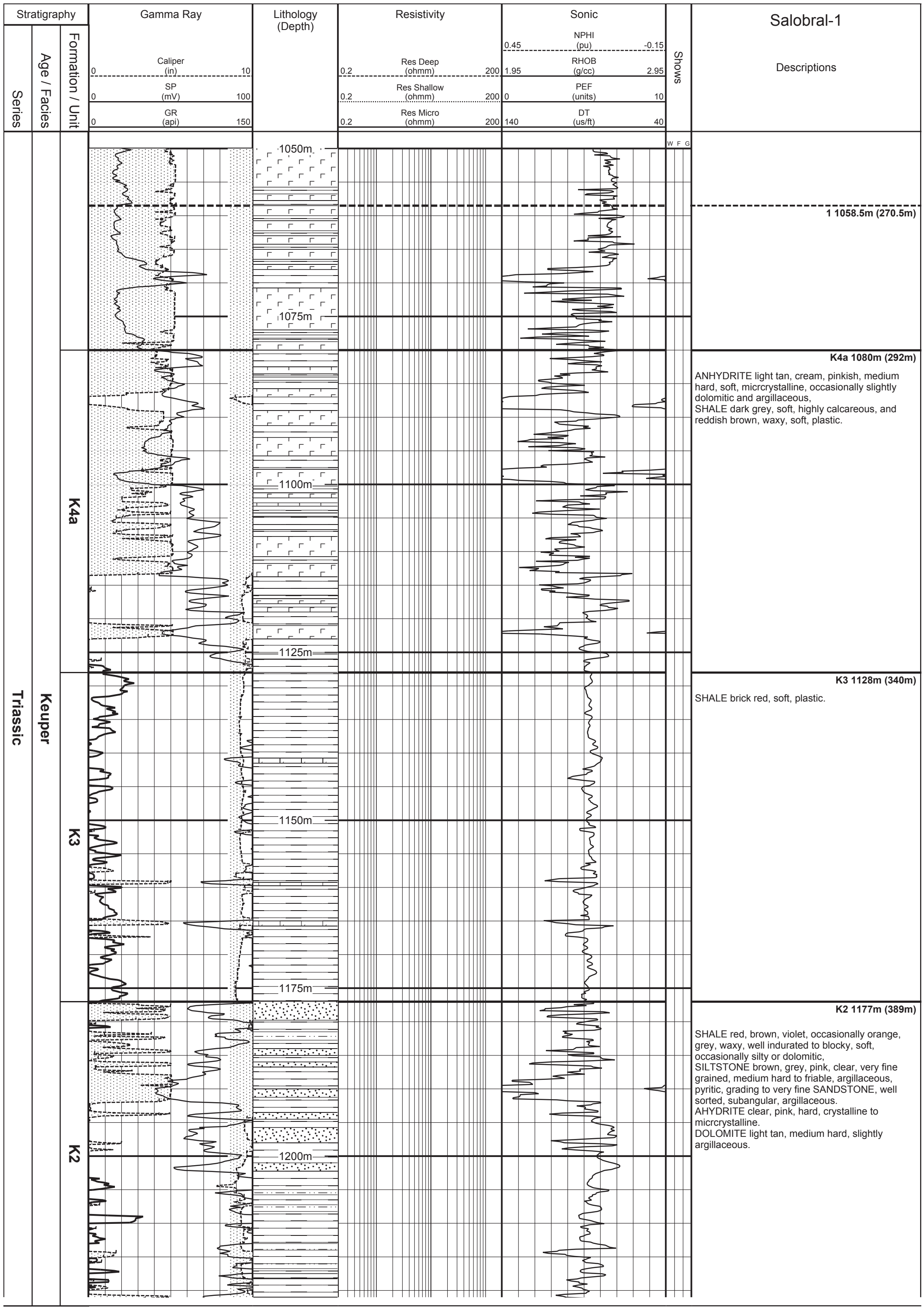

Fig. 9.- Salobral-1 composite log, K3, K4a sections
Fig. 9.- Salobral-1 log compuesto, intervalos K3, K4a

Triassic ones. Mispicking of this level can lead to assign K4-K5 evaporites to the Anhydrite Zone (Castillo-Herrador, 1974), or the opposite, placing part of the Anhydrite Zone in the Keuper (Gómez and Goy, 1998). In Ledaña-1 and Carcelén-1, K6 picking is not very obvious, but K5 and base of Anhydrite Zone log electrofacies restricts very much the uncertainty, nevertheless the absence, faulted out, of this unit can not be categorically excluded. Despite being described often as dolomites, grey to tan, microcrystalline, partly anhydritic, on the logs can be observed a lower clean peak followed by a radioactive shaly level, before entering in the main dolomitic body.

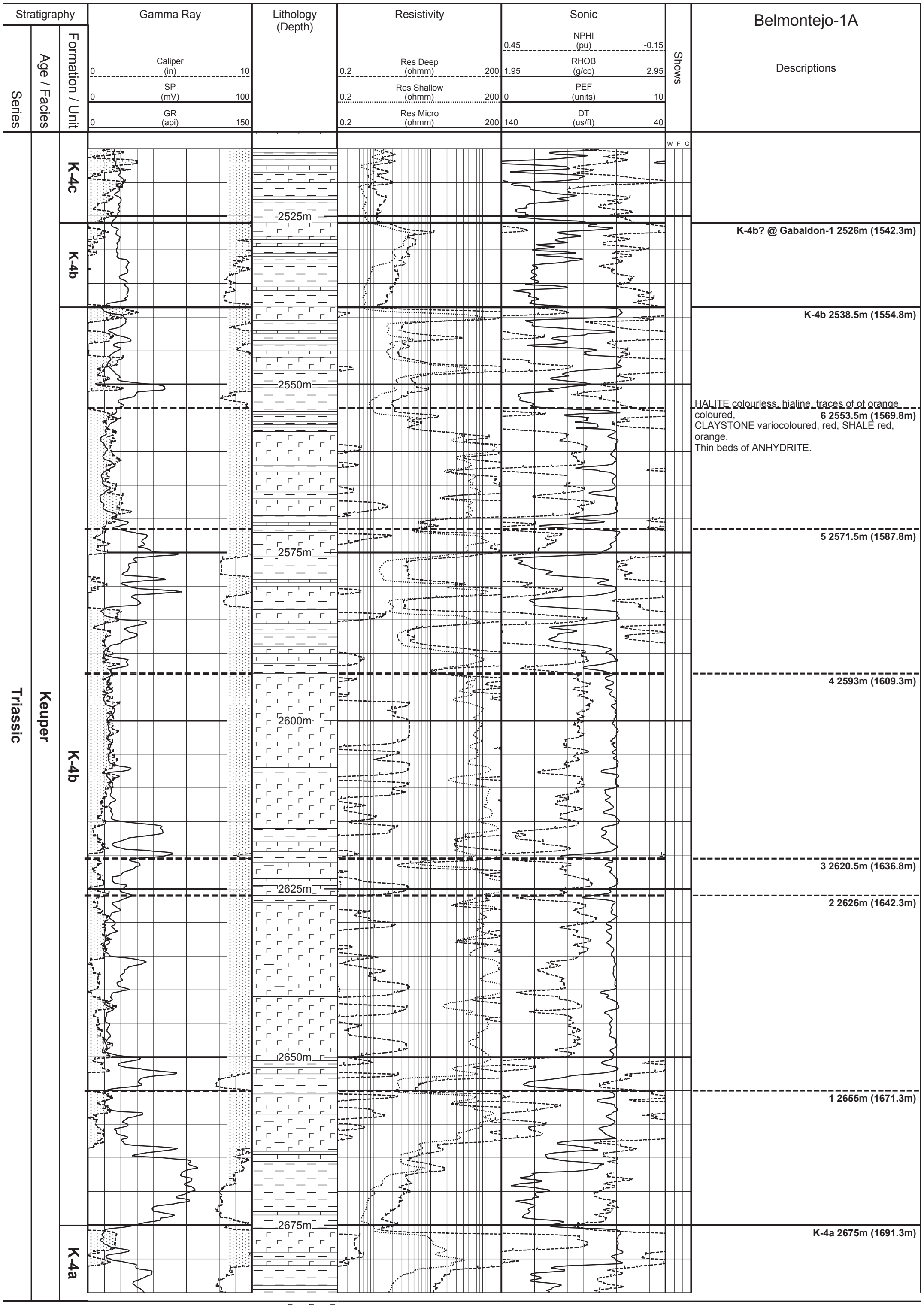

Fig. 10.- Belmontejo-1A composite log, K4b section

Fig. 10.- Belmontejo-1A log compuesto, intervalo K4b

If this interpretation is right, although no red or sandy levels are mentioned in the cuttings description, except in Gabaldón-1 well, K6 will be in this domain more similar to Zamoranos Fm. than to Imón Fm. (Pérez-López *et al.,* 1994).

The Lower Lias consists in most of the wells of the Anhydrite Zone (Castillo-Herrador, 1974), equivalent to Lécera Fm., (Gómez and Goy, 1997), and Cuevas Labradas Fm. (Goy *et al.,* 1976). The Anhydrite Zone, AZ (Fig. 12), is a thick alternation of anhydrite and dolomite in metric to decimetric levels. Its lower part lies over K6 unit, Imón/Zamoranos Fm., in most of the wells, except in Gabaldón-1 and Belmontejo-1A, where a 300-400m section of massive evaporites, Lower Salt Zone, LSZ, is present (Fig. 13), mostly halite, with interbedded anhydrite, shale and dolomite levels. The remainder of the Anhydrite Zone can be divided into three units, the Lower Anhydrite Zone, LAZ, formed by an alternation of anhydritic and dolomitic levels, with thin beds of shales, but as a whole having an anhydritic dominant character; the Middle Anhydrite Zone, MAZ, with a very characteristic limestone level, in general more carbonatic than anhydritic, in contrast with the lower unit; and a third level, the Upper Anhydrite Zone, UAZ, that is more similar to the lower level, but shows a less uniform anhydritic character in some wells (Fig. 12). The anhydrites can be described as white to grey, well bedded to nodular, dolomites are grey, crystalline, some times anhydritic, shales

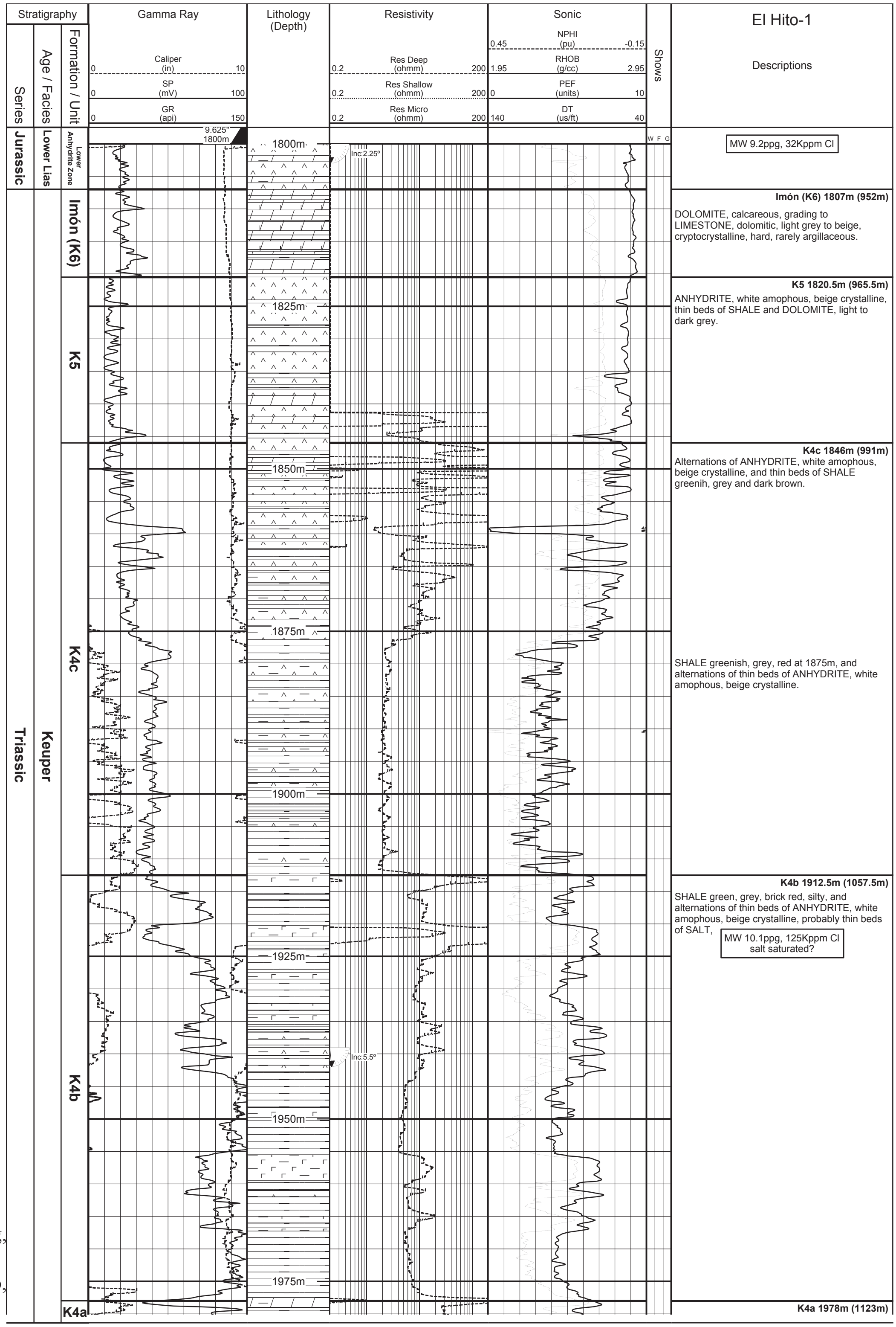

Fig. 11.- El Hito-1 composite log, K4c, K5, K6 sections

Fig. 11.- El Hito-1 log compuesto, intervalos K4c, K5, K6

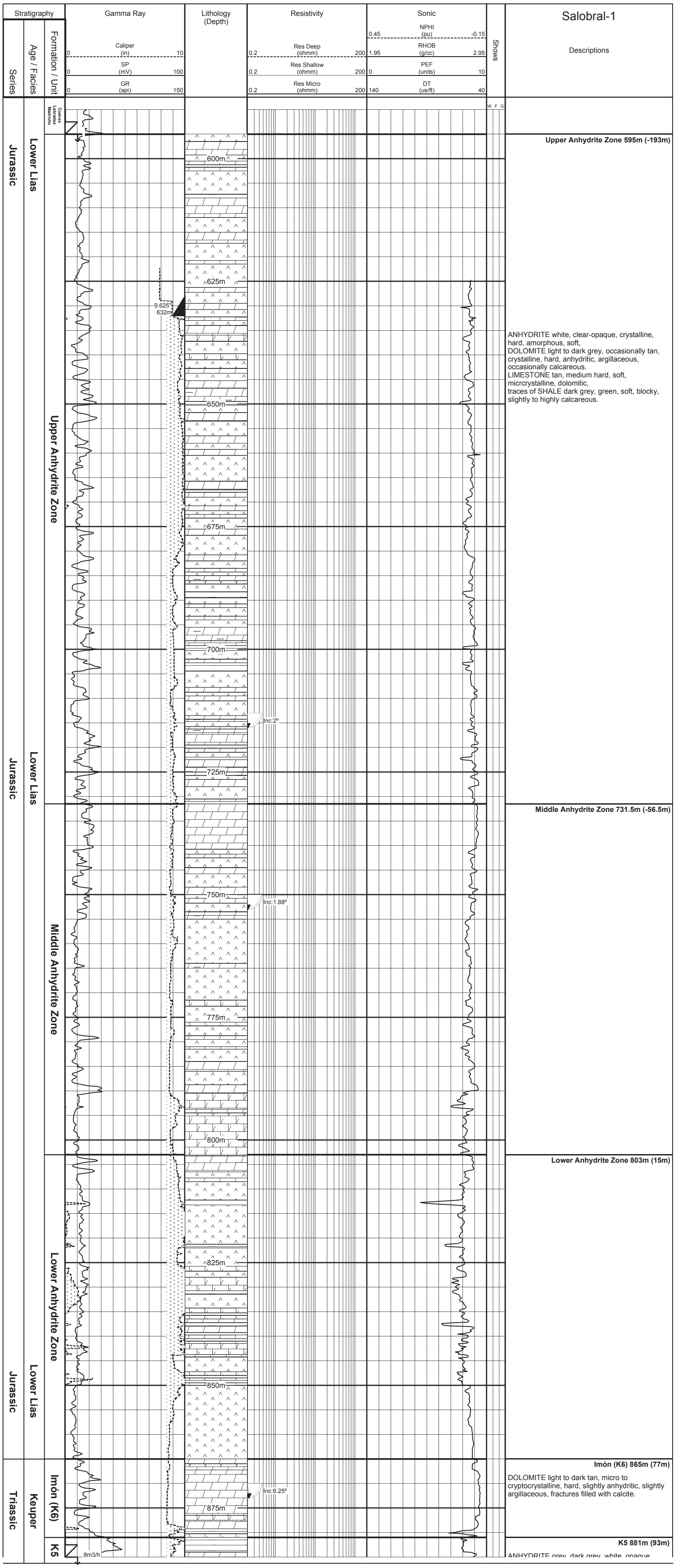

Fig. 12.- Salobral-1 composite log, K6, AZ sections
Fig. 12.- Salobral-1 log compuesto, intervalos K6, AZ

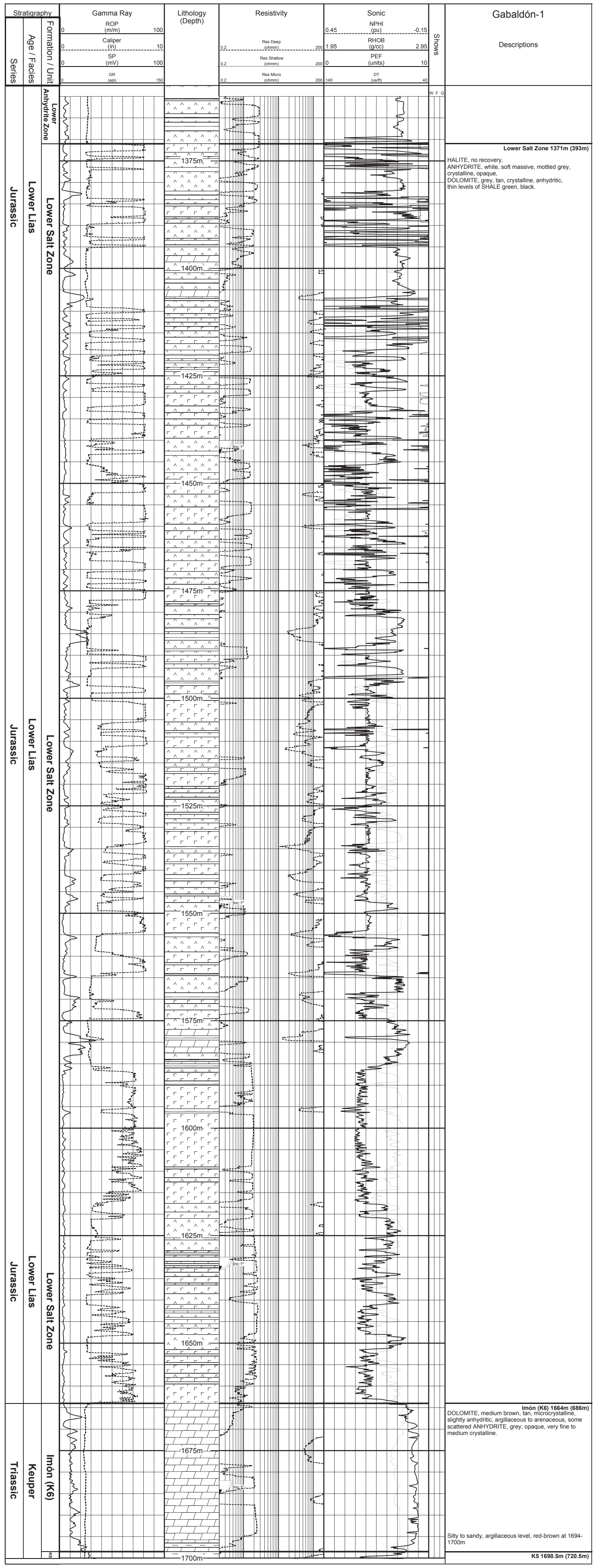

Fig. 13.- Gabaldón-1 composite log, K6, LSZ sections
Fig. 13.- Gabaldón-1 log compuesto, intervalos K6, LSZ

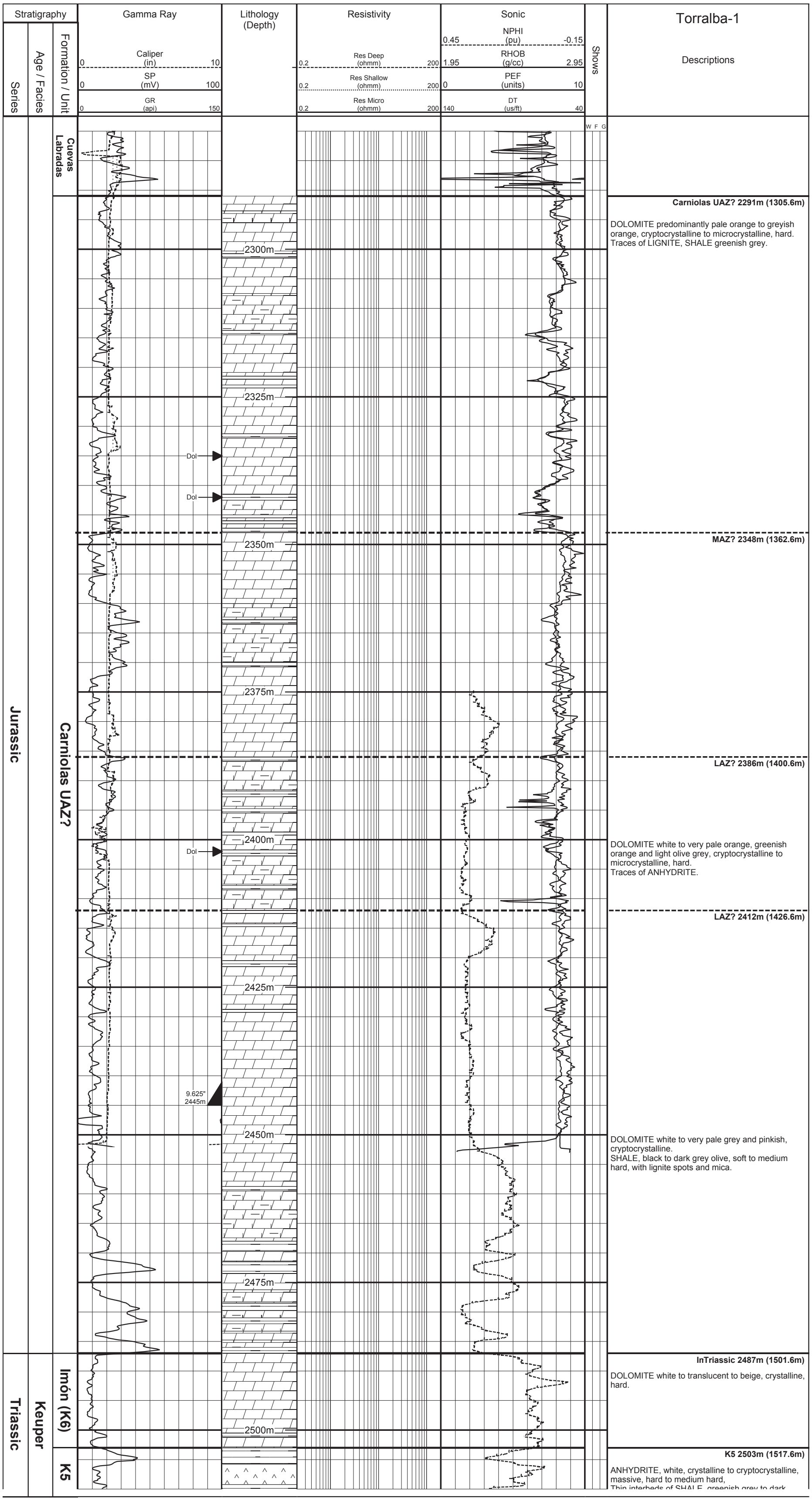

Fig. 14.- Torralba-1 composite log, K6, AZ sections

Fig. 14.- Torralba-1 log compuesto, intervalos K6, AZ

are usually grey to black or green. Thickness for the three units ranges respectively from 60-380m, 70-140m and 130-300m.

Another interesting exception is Torralba-1, in which a dolomitic interval overlies directly K6 unit (Fig. 14). Whether these dolomites belong to the Middle Anhydrite Zone or are the result of the dissolution of the anhydrites, becoming the carniolas of Cortes de Tajuña Fm. is still debatable. A similar case is present in El Hito-1, but here it is restricted to the Upper Anhydrite Zone, which is mainly dolomitic, rather than anhydritic.

In all the central group wells the contact with the overlying Cuevas Labradas Fm. is clear and sharp; thickness for this section is very constant, 90-120m.

An exception to most of the results previously mentioned is Jaraco-1. This well shows a Buntsandstein section, made up of several fining upward sections, 675m thick, in spite the well not having reached the Hercynian basement. Also the Muschelkalk is thick, total 310m. The lower part, 100m thick, consists of alternating dolomites and anhydrites and could be assigned to M2, a marine equivalent of the western M2 described earlier. The upper massive dolomitic part, up to 210m thick, can be assigned to M3, but in this well no distinction between M3a and M3b is possible. All the Keuper and lower Lias units, K1-K6 and AZ, are present, keeping their evaporitic or clastic character, but much thinner. K1 includes volcanics and breccias. Proper identification of Imón Dolomite (K6) is still debatable, as K5 facies are very similar to the overlying Anhydrite Zone ones.

From the structural point of view most of the wells where dips have been measured, either on dipmeter or cores, show very low values, 0-15º, so well thickness should be close to real. No data has been available to us in key wells like Belmontejo-1A and Gabaldón-1, in which repetitions of K2-K3, and M2-M3-K1, respectively, have been identified. Seismic line interpretation in general supports this almost flat geometry (Bartrina *et al.*, 1990).

4. Petroleum Geology

Two main points will be treated in this point, reservoir rocks and source rock potential.

Regarding reservoirs, the main reservoirs with matrix porosity should be considered Buntsandstein and K2 sandstones. Buntsandstein shows very low porosities, most of them below 10%; descriptions include silica, ferruginous or even dolomitic or anhydritic cement.

The same comments are valid for K2 unit, Manuel Sandstone. Reservoirs in this formation are much thinner and have suffered extensive damage, with anhydrite or even halite filling the pore space.

The only exception is Tribaldos-1 well, with porosities around 10-15%, but it is to be reminded that in this well the Triassic section was not buried to comparable depths as the rest of the wells.

K6 unit and Mushelkalk, mainly M3a, carbonates show no matrix porosity, but mud losses have been reported while drilling these sections and fractures are also mentioned in core descriptions.

Source rock potential could be present in the pre-evaporitic shaly sections and plant debris rich levels of K2 unit. Outcrop and well samples show TOC values up to 1.5-5.5%, but hydrogen index is always below 200, so pointing to kerogen type III. Maturity based on Tmax and vitrinite reflectance show most the samples about entering the oil window.

5. Results and discussion

Cross sections were prepared at the top of several formations considered to be key markers for the sequence stratigraphy arrangement, and basin evolution illustration (Figs. 15-19).

At the top M3 unit boundary (Fig. 15) it can be observed the relatively thin sections of Buntsandstein and Muschelkalk being sedimented on a very flat lying platform, the shoulders of rift geometry described for the Iberian Range, and exemplified here by Jaraco-1 well. M2 clastic sediments, with thin carbonatic-evaporitic levels are always underlying M3, main carbonate body, and clearly different from Buntsandstein units. According to available data, M2 clastics and evaporites were deposited in tidal environments. M3 marine carbonates were also deposited on very shallow platforms, under normal salinity to slightly hypersaline conditions, resulting in a shallowing upward section, with ferruginous levels, hard grounds and evaporite casts at the top. This unit is present as far west as Tribaldos-1 and still identifiable. In Gabaldon-1 well, K1-M3-M2 tectonically repeated sections should be subtracted to accommodate thicknesses properly, approximately 80m.

At the top K3 unit (Fig. 16), two different K1-K3 domains can be identified, the western one with thin complete sections, which still maintain their saline units, except in Tribaldos-1 well again, and a central domain with thick, well developed saline K1 and clastic K2, K3 units.

For K1, geochemical data (Br, Sr, $\delta^{18}O$, $\delta^{34}S$) show that the evaporites are of marine origin and in full connection with oceanic water supply (Ortí *et al.*, 1994; Utrilla *et al.*, 1992). This unit was deposited, mainly, under very shallow subaqueous coastal salina arid conditions, forming evaporitic 4 to 5th order shallowing upward sequences, about 5-25m thick. Some of the sequences even reach

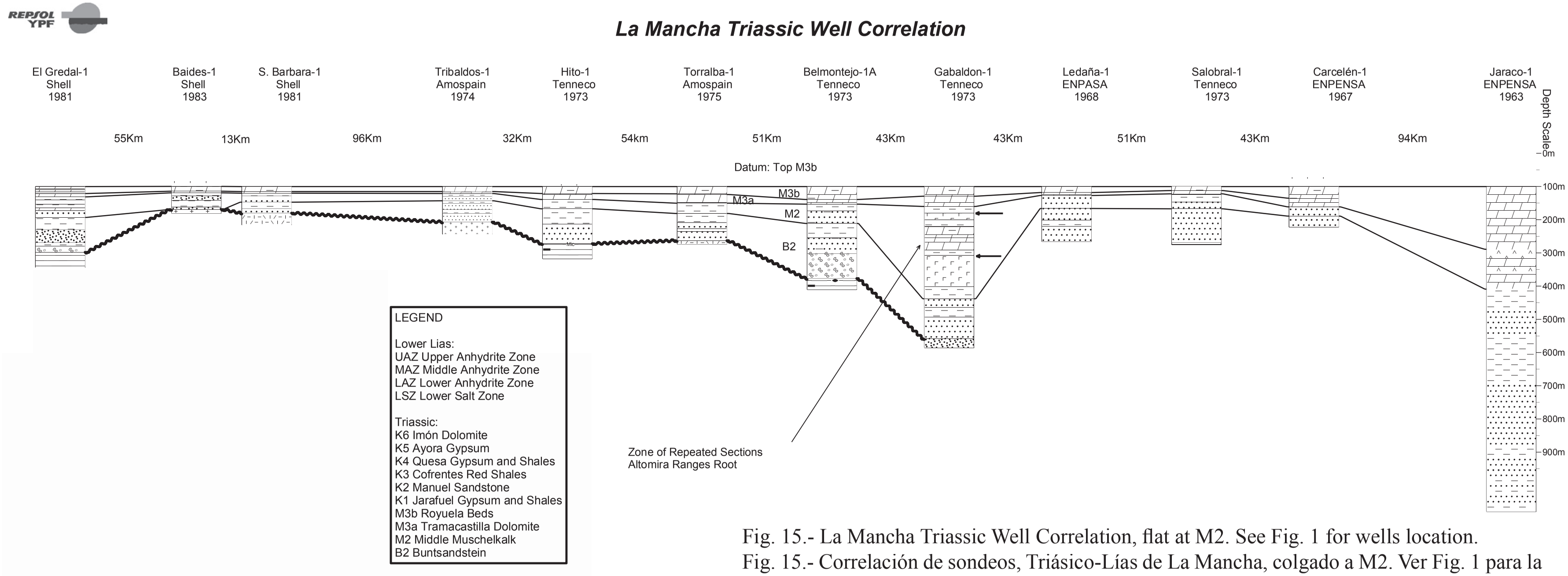

Fig. 15.- La Mancha Triassic Well Correlation, flat at M2. See Fig. 1 for wells location.

Fig. 15.- Correlación de sondeos, Triásico-Lías de La Mancha, colgado a M2. Ver Fig. 1 para la lacalización de los sondeos.

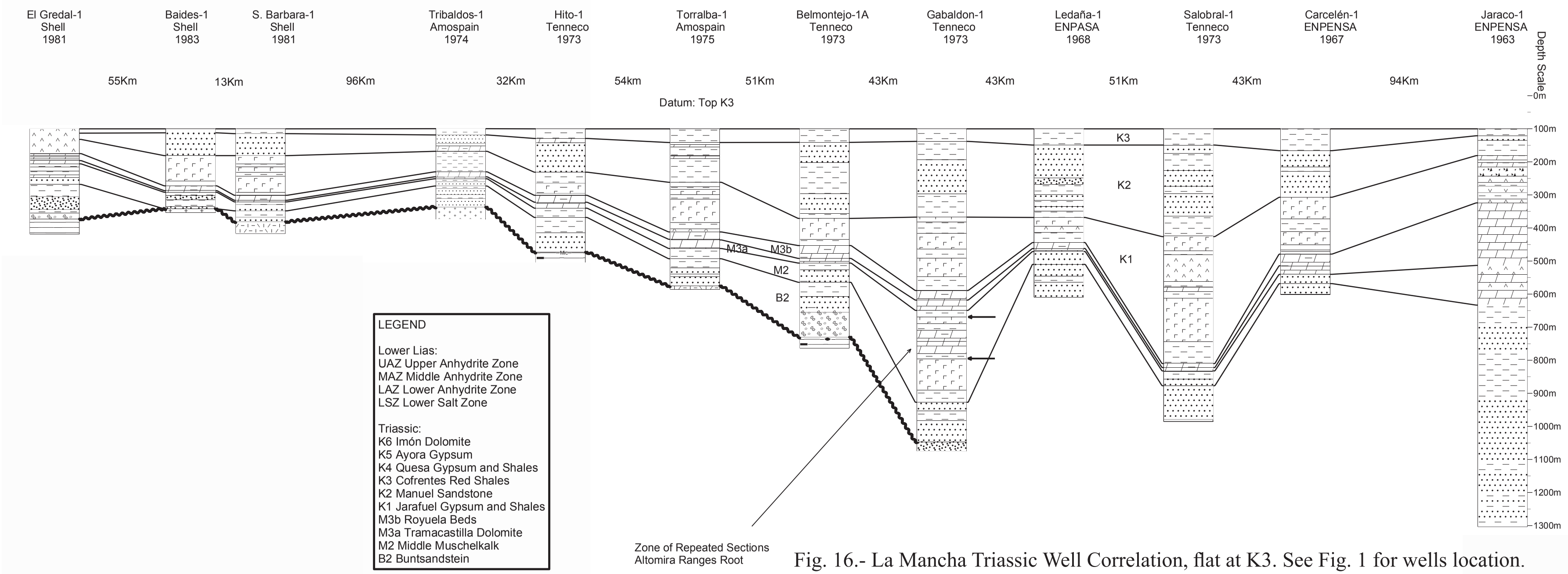

Fig. 16.- La Mancha Triassic Well Correlation, flat at K3. See Fig. 1 for wells location.

Fig. 16.- Correlación de sondeos, Triásico-Lías de La Mancha, colgado a K3. Ver Fig. 1 para la lacalización de los sondeos.

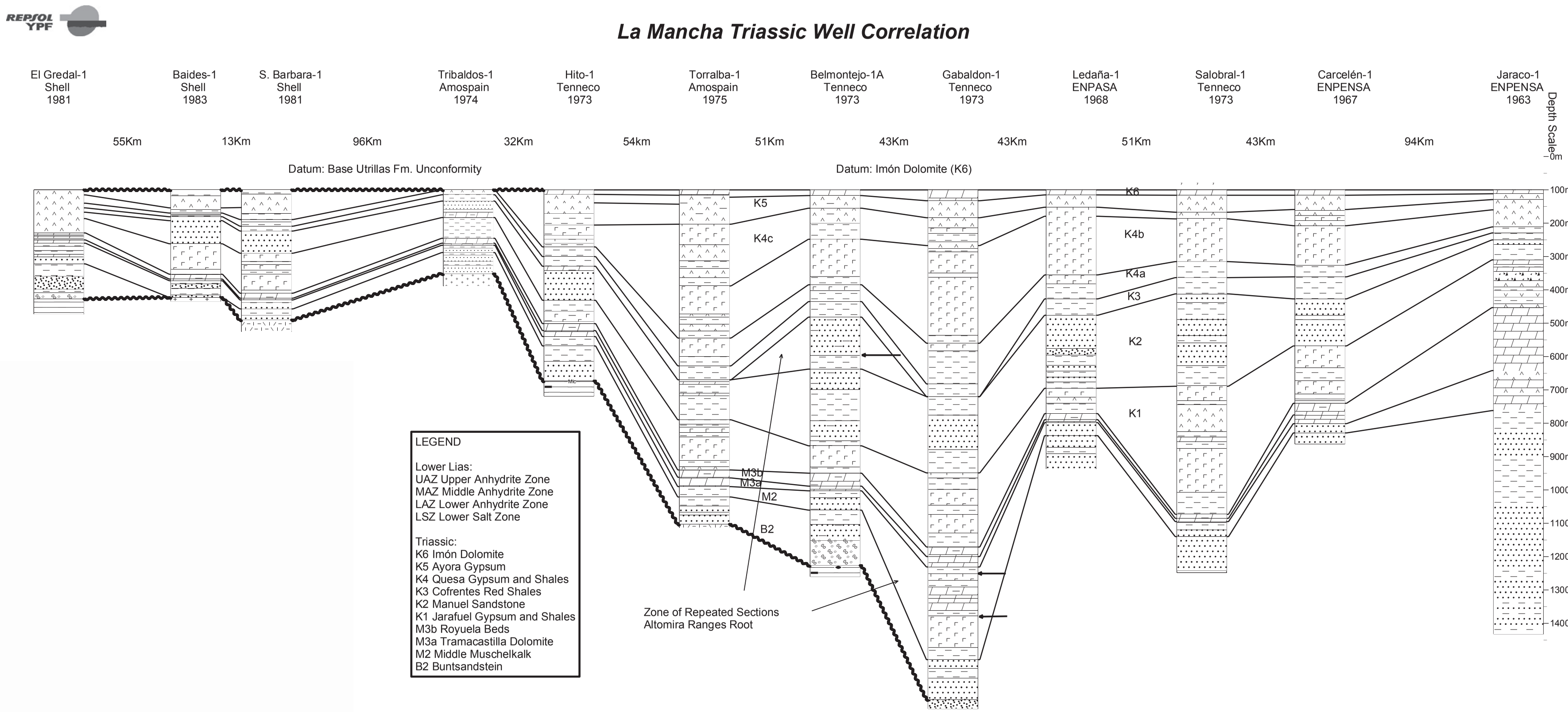

Fig. 17.- La Mancha Triassic Well Correlation, flat at K6. See Fig. 1 for wells location.

Fig. 17.- Correlación de sondeos, Triásico-Lías de La Mancha, colgado a K6. Ver Fig. 1 para la lacalización de los sondeos.

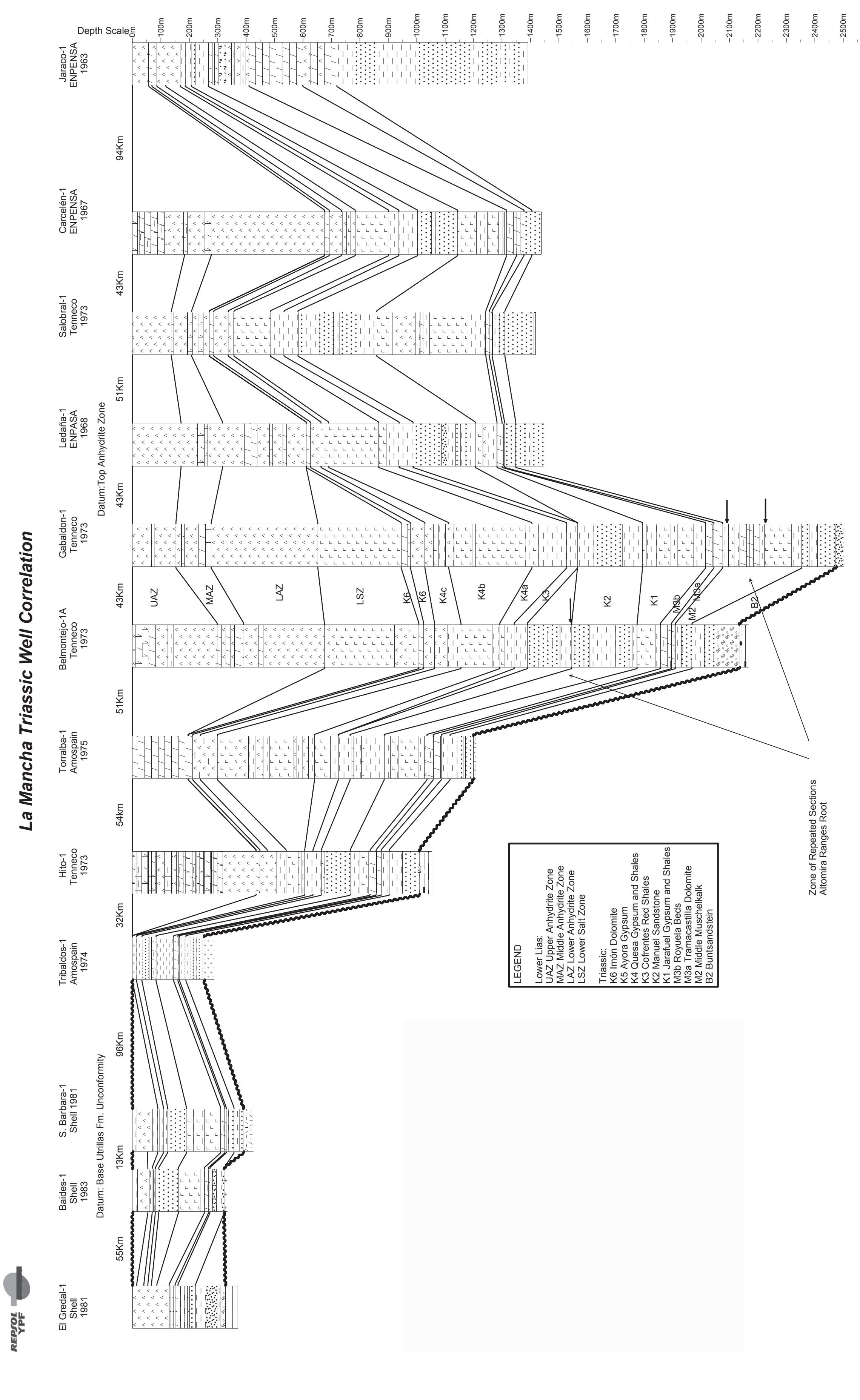

Fig. 18.- La Mancha Triassic Well Correlation, flat at AZ. See Fig. 1 for wells location.
Fig. 18.- Correlación de sondeos, Triásico-Lías de La Mancha, colgado a AZ. Ver Fig. 1 para la lacalización de los sondeos.

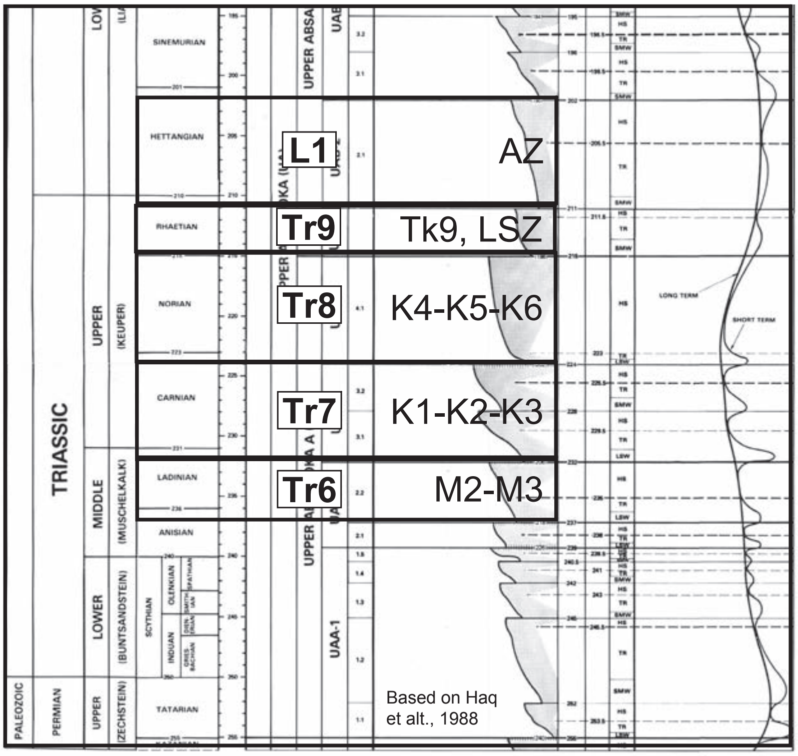

Fig. 19.- La Mancha Triassic-Lias Formations sequence stratigraphy

Fig. 19.- Estratigrafía secuencial de las formaciones del Triásico-Lias de La Mancha

sabkha stage at their very top. This sabkha stage may be relatively more frequent in outcrops, for the reasons mentioned before, but may only reflect a partial view of the full data set.

This arid evaporitic environment was subtly modified by a climate-propelled clastic event in K2. This unit shows clear sand fairways, specially in the central wells group, but also shows that, in the absence of sand rich bodies, mild evaporitic conditions were still recurrent, presence of anhydritic and dolomitic levels, but a total absence of halite levels. Palinological data, abrupt increase of spores content (Torres, 1990), as well as abundant equisetal plants debris, point to a relative humid event during K2 times. The previous very shallow coastal salina was prograded by a distal lower alluvial plain, with generally small and shallow channels, with ephemeral but intense floods. In some areas they could appear even stable anastomosed channels or even reach marine tidal flats.

K3 is a mud flat on a lower coastal plain, subject to occasional marine conditions pointed by thin but persistent dolomitic levels, marking the end of the previous humid event and the return of the arid conditions at the top of this sequence. In Belmontejo-1A well, K3-K2 tectonically repeated sections should be subtracted to accommodate thicknesses properly, about 156m.

At the top K6 unit flattening, similar comments can be made, the northern group of wells show a much thinner Keuper sections, where preserved, and the topmost interval, mainly top K4, K5 and K6 has been eroded prior to Utrillas Fm. deposition. Here Tribaldos-1 also marks the more incomplete well.

K4-K5 is composed by several complete evaporitic 4 to 5th order shallowing upward sequences, 5-25m thick. Geochemical data comments for K1 are also applicable to K4-K5 units. The sedimentary environment was quite similar to K1: coastal salina, but the evolution in time has substantial differences. In the lower part, K4a, these sequences are poorly developed, and most of them only reach the shaly pre-evaporitic stage. In the medium part, K4b, the evaporitic sequences are fully developed and reach the halite stage, maximum brine concentration of the K4-K6 sequence. Above this point, the K4c and K5 evaporitic sequences are not so well developed and do not pass the anhydrite stage, thus marking an inversion in the brine concentration trend. K5 is even more diluted comparatively as many of these evaporitic sequences only remain in the dolomite stage.

K6 carbonates are sedimented under very shallow water conditions, and have a shallowing upward character, passing from oolitic grainstones at the base to laminated mudstones with algal mats, and even evaporite crystals casts to the top.

So K4-K6 units form together a huge 3rd order evaporitic shallowing upward sequence, which "dilutes" upwards, from halite, to anhydrite and culminates with a dolomite stage, due to the persistence of the high sea level.

At top AZ unit flattening similar comments can be made, the northern group of wells are excluded of this analysis, as this unit is not preserved below Utrillas Fm. unconformity. In the central group, two wells show a basal halite section, Lower Salt Zone, which does not exist in the contiguous wells. Also can be seen the “carniolization” of the Anhydrite Zone, either complete (Torralba-1) or partial (El Hito-1), by dilution of the sulphate component and subsequent brecciation of the carbonate one. Similar comments can be made as the ones for K1 and K4-K5 units, regarding geochemical data. Most of these sediments were laid down under arid coastal salina conditions; they form small evaporitic sequences, ranging only from dolomite to anhydrite stages, with the exception of the Lower Salt Zone, which has more complete sequences, shale to halite stages. The Middle Anhydrite Zone, much richer in carbonates, than the surrounding units, could correspond to a more humid event in the middle part of this sequence, as palinological data tentatively interpretation show.

For these last three sequences, is clear that more accommodation space has been made available for thick sequences to be deposited in La Mancha area, while the shoulders of this basin have been continuously pushed to the West and Southwest. These evaporite filled grabens, either generated by “rifting” or “thermal cooling”, are at least comparable to the ones described for the Buntsandstein and Permian Units, both in area extent and thickness, as even incomplete previous isopach maps show (Castillo-Herrador, 1974; Ortí, 1974; Torres *et al*., 1990). Evaporite dissolution in outcrops could be an explanation, but not anymore an excuse to miss and acknowledge its existence.

An attempt is presented to tie these sequences to Mesozoic sea level change cycle chart, Haq *et al*. (1998), specially to the relative change of coastal onlap column (Fig. 19). According to the previously discussed sequences and the available biostratigraphic data in the references, four to five distintictive sequences can be established: Tr6 sequence includes M2 and M3 units, its age is in general Ladinian, but could reach even uppermost Anisian; Tr7 sequence comprising K1, K2 and K3 units, in general of Carnian age; this sequence is a compound one according to the coastal onlap chart, although this break is minor compared to their respective top and bottom boundaries. This minor break could be tied either to the lowermost halite cycle present in Salobral-1 and Carcelén-1, or alternatively to the base of K2. Tr8 sequence includes K4, K5 and K6, Imón/Zamoranos, units, in general of Norian age. Tk9 corresponds to the Lower Salt Zone of the Anhydrite Zone, and will represent the Rhaetian age based only on the correlation with the coastal onlap chart, as there are no biostratigraphic data available to support this age; but top Zamoranos Fm. hardly reaches uppermost Norian. L1 sequence corresponds to the Anhydrite Zone, and shall correspond to the Hettangian, based on the age of the lower Cuevas Labradas Fm., early Sinemurian. Buntsandstein has been left outside of this scheme (López-Gómez and Arche 1993).

As most of these sediments were deposited in very shallow waters to lower coastal plain environments, no significant water depth changes have been documented and sedimentation rates could be calculated from their respective time span. Sedimentation rates based on the previous points are 68-75m/My for the Anhydrite Zone (L1 sequence), 73-83m/My for the Lower Salt Zone (Tr9 sequence), 22-65m/My for the K4-K5-K6 (Tr8 sequence), 20-89m/My for the K1-K2-K3 (Tr7 sequence), and 9-20m/My for the M2-M3 (Tr6 sequence). In the ranges for the Tr8 to Tr6 the lower values generally represent the northern group wells, while the higher values represent the central group wells. For comparison purposes, Cuevas Labradas Fm. shows a very homogeneous 7-9m/My rate.

If Cuevas Labradas, and Anhydrite Zone rates are valid examples, disaggregated values for K4-K5 units will range from 27-81m/My, K2-K3 units will range from 11-43m/My, and 11-29m/My for M2 unit. If we recalculate rates for Tr7 for the upper cycle, rates will be duplicated. These data show that evaporite rates are on average 120m/My for the K1 halite intervals, 20-90 m/My for the clastic intervals K2-K3. This analysis will also supports the assignment of the Lower Salt Zone to the Rhaetian, and the minor break in Tr7 to the lowermost halite cycle of K1.

6. Conclusions

La Mancha Area is a zone where Tertiary are the main outcrop rocks, so only wells can help to establish the lowermost Mesozoic stratigraphy. From the study and correlation of the above-mentioned wells several conclusions can be extracted (Figs. 15-19):

1) Below the Muschelkalk there is a correlatable clastic unit with thin-layered anhydrites and dolomites, different from the Buntsandstein units, interpreted as M-2, which we consider as equivalent of the clastic-evaporitic Middle Muschelkalk, further to the Northeast (Fig. 15). Accordingly Iberian Triassic definition should be modified to include M2 clastic event. Some Buntsandstein assigned intervals may become M2 too (Pérez-Valera *et al*., 2000).

2) Keuper units K1 to K6 are quite correlatable across the area, wells and outcrops, maintaining their evaporitic, clastic or carbonatic character (Figs. 16, 17).

3) Lower Lias Anhydrite Zone is present in all the central area, and shows a thick saline unit above the K6 unit, Imón Dolomite, in the southwestern most part of the zone (Fig. 18).

4) Evaporitic sequences are quite common in the K1, K4 units. A lower shaly pre-evaporitic section, corresponding to the transgressive, and an upper saline section, forming the highstand part respectively, compose these sequences.

5) The Upper Muschelkalk, M2 and M3, Tr6 sequence, could be interpreted as a shallowing upward sequence, being M2-M3a the transgressive part, and M3b the highstand section. According to available biostratigraphic data this unit ranges from Uppermost Anisian to Upper Ladinian. These sections were deposited on a very flat ramp area, as the Buntsandstein was (Figs. 15, 19).

6) The Lower Keuper, K1-K3, Tr7 sequence, could be interpreted as a shallowing upward sequence that rather "diluting upwards", becomes clastic due to climatic reasons, and ends in a mud flat for K3, marking the sequence boundary (Fig 16, 19). This unit will be Carnian s.l. based on the few biostratigraphic data available.

7) The Upper Keuper, K4-K6, Tr8 sequence, can be interpreted as a shallowing upward sequence, in which K4a is the pre-evaporitic section, and K4b, K4c and K5 form the bulk of the evaporitic section, corresponding to the highstand, but as it is diluting upwards, halite is being substituted by anhydrite, and is caped by a dolomitic level K6, marking the top of the of the highstand (Figs. 17, 19). The age of this unit could be assigned to Norian.

8) The Anhydrite Zone, L1 sequence, is also interpreted as a shallowing upward sequence, also diluting upwards, rather than concentrating upwards. Its age should be Rhaetian-Hettangian (Figs. 18, 19). At this moment there are not sufficient biostratigraphic data to support to break up this sequence in a Lower Salt Zone, Tr9 sequence, Rhaetian, from the main Anhydrite Zone, L1 sequence, Hettangian, so our interpretation is based mainly on the presence of this unit in Belmontejo-1A and Gabaldón-1 wells. If this proves to be correct, Rhaetian age sediments have little chance to be represented on field outcrops.

9) The two thickest sections for the Keuper and the Anhydrite Zone are superposed geographically on top of each other and offset from the thickest sections for Muschelkalk and Buntsandstein, located further to the East and Northeast (Fig.18).

10) Gross sedimentation rates based on the previous points are 68-75m/My for the Anhydrite Zone (L1 sequence), 73-83m/My for the Lower Salt Zone (Tr9 sequence), 22-65m/My for the K4-K5-K6 (Tr8 sequence), 20-89m/My for the K1-K2-K3 (Tr7 sequence), and 9-20m/My for the M2-M3 (Tr6 sequence). For comparison purposes, Cuevas Labradas Fm. shows a very homogeneous 7-9m/My rate. Corrected values for disaggregated intervals and lithologies have been recalculated.

11) Two subsidence regimes can be interpreted for the Triassic and lower Lias units: a stable regime, 10-20m/My, active for the Buntsandstein and Tr6 sequences in all the wells except Jaraco-1, and Tr7-8 sequences in the northern group wells plus Jaraco-1; and a subsident one, 40-120m/My, active for Buntsandstein and Tr6 only in Jaraco-1, and Tr6 to L1 in the central well group.

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