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Palynostratigraphy and paleoenvironment of the South Rifian Ridges (Morocco) Upper Domerian-Lower Toarcian sequence: A transitional domain between the Proto-Atlantic and the Tethys

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ABSTRACT

This paper relates to two marly outcrop sections of the South Rifian Ridges central unit (Moulay Idriss Zerhoun area), dated by Upper Domerian-Lower Toarcian ammonites. The Upper Domerian marls from the SKM outcrop section (Souk of Moulay Idriss Zerhoun) have yielded palynofacies very rich in lignitic particles (needle-like phytoclasts), Tasmanites (unicellular green algae), spores and pollen grains. The marine microfossils, especially dinoflagellate cysts and acritarchs, are not present. These latter marine organisms are predominant in the Lower Toarcian palynofacies samples collected from the FA (Feddane Amar) outcrop section, in association with a significant amount of lignitic particles. This striking difference in the palynological content between the palynofacies of the Upper Domerian and the Lower Toarcian indicates an important change in the marine paleoenvironment in the South Rifian Ridge domain. Therefore, the anoxic period during the Upper Domerian is marked by the abundance of spores and pollen grains and the absence of marine microfossils, except for the Tasmanites; it is followed by a normal salinity-marine period, characterized by abundant marine-related palynomorphs, in the Early Toarcian. This paleoenvironmental change may be related with the Middle Liassic carbonate platform dislocation of the South Rifian Ridge domain and probably to the global marine transgression, occurring at the base of Toarcian, known all over the world.

Key words: palynofacies, palynostratigraphy, Middle-Upper Liassic transition, South Rifian Ridges, Morocco

Palinoestratigrafía y paleoambiente de la secuencia del Domeriense superior-Toarciense inferior de la Sierra Sur-Rifeña (Marruecos): Un dominio transicional entre el Proto-Atlántico y el Tetis

RESUMEN

El presente trabajo se refiere a dos secciones de afloramientos margosos de la unidad central de las Sierras Sur-Rifeñas (área de Moulay Idriss Zerhoun), datadas por ammonites del Domeriense superior-Toarciense inferior. Las margas del Domeriense superior de la sección del afloramiento SKM (Zoco de Moulay Idriss Zerhoun) han proporcionado palinofacies muy ricas en partículas leñosas (fitoclastos aciculares), Tasmanites (algas verdes unicelulares), esporas y granos de polen, mientras que no se han encontrado microfósiles marinos, especialmente quistes de dinoflagelados y acritarcos. Estos últimos organismos marinos predominan en las muestras de palinofacies del Toarciense inferior recogidos en la sección del afloramiento FA (Feddane

Amar), en asociación con una cantidad importante de partículas leñosas. Esta marcada diferencia en el contenido palinológico entre las palinofacies del Domeriense superior y del Toarciense inferior indica un cambio importante en el paleoambiente marino en el dominio de las Sierras Sur-Rifeñas. Por lo tanto, el período anóxico durante el Domeriense superior está marcado por la abundancia de esporas y granos de polen, y la ausencia de microfósiles marinos, con excepción de Tasmanites, seguido en el Toarciense inferior por un período marino de salinidad normal, caracterizado por abundantes palinomorfos relacionados con el mar. Este cambio paleoambiental podría estar relacionado con la dislocación de la plataforma carbonática del Liásico medio en el dominio de las Sierras Sur-Rifeñas y, probablemente, con la transgresión global marina que tuvo lugar en la base del Toarciense, conocida en el mundo entero.

Palabras clave: palinofacies, palinoestratigrafía, transición del Liásico medio-superior, Sierras Sur-Rifeñas, Marruecos

VERSIÓN ABREVIADA EN CASTELLANO

Introducción y objetivo del estudio

Este trabajo, el primero de palinología del Jurásico inferior del margen meridional de Tetis, se basa en el análisis de dos secciones, SKM y FA (Sierra Sur-Rifeña), datadas por ammonites del Domeriense superior-Toarciense inferior. El residuo orgánico de 12 muestras indica una palinofacies rica en material leñoso y en microfósiles marinos o continentales. Esto permitió un análisis bioestratigráfico y paleoambiental del dominio de las Sierras Sur-Rifeñas en la transición del Liásico medio al Liásico superior.

Sector estudiado y localización de las secciones

Las Sierras Sur-Rifeñas corresponden a un grupo de macizos jurásicos que forman parte del antepaís de la cadena o Cordillera del Rif (Figs. 1 y 2). Faugères (1978a) distingue tres unidades en el sustrato jurásico, equivalentes a zonas paleogeográficas (Figs. 2 y 3): unidad periférica, con dos formaciones de edad, Triásico-Liásico medio (Fig. 3); unidad intermedia, con margas limosas del Toarciense-Bajociense medio; unidad central, con series pelágicas del Liásico medio-Bajociense medio, correspondientes al centro de la cuenca. En esta última unidad se levantaron dos secciones SKM y FA. La primera, cerca del Zoco de Moulay Idriss, se compone de margas limosas del Domeriense superior; la segunda, 3 km al este, se compone de margas grises, que pasan a margas amarillas con ammonites del Toarciense inferior. Se analizaron 4 muestras del Domeriense superior y 8 del Toarciense inferior.

Resultados palinológicos

El residuo orgánico del Domeriense superior (Fig. 4 y Fig. 6) muestra dos tipos de materia orgánica: una de origen continental (Mob), constituida por fitoclastos (20 a 40%) y rica en restos de madera en forma de agujas, y otra marina (Mov), menos abundante (5 a 10 %), constituida por cutículas y epidermis de células vegetales. Las esporas y pólenes (Fig. 5) están representados por: Alisporites robustus *(Fig. 7J),* Classopollis *sp. (Fig. 7I),* Kraeuselisporites reissingeri *(Fig. 7B),* K. reissingeri *(gr.) (Fig. 7C-E),* Neoraistrickia *sp.,* Quadraeculina anellaeformis *(Fig. 7K) y* Retitriletes *sp. (Fig. 7G-H). Los escasos palinomorfos marinos están representados por Tasmanáceas. Los dinoflagelados y los acritarcos están ausentes. La palinofacies del Toarciense inferior es del tipo Mob en un 95%, mientras que el tipo Mov es > 5%. Las esporas y pólenes (Fig. 6) están representados, además de las formas del Domeriense superior, por:* Ischyosporites variegatus *(Fig. 7F),* Callialasporites dampieri *(Fig. 7A), y C.* trilobatus. *Los acritarcos están dominados por el género* Michrystridium. *Los dinoflagelados están representados por* Dissiliodinium giganteum *(Fig. 7O),* Luehndia spinosa *(Fig. 7L),* L. cirilliae *(Fig. 7P),* Mancodinium semitabulatum *(Fig. 7M-N),* Nannoceratopsis gracilis *y* Phallocysta eumekes.

Análisis paleoambiental

El residuo del Domeriense superior (Fig. 4 y Fig. 6) muestra una palinofacies dominada por formas continentales: esporas, pólenes y fitoclastos (Mob), incluyendo Tasmanáceas. La presencia de fitoclastos es importante para la reconstrucción del paleoambiente. La forma de aguja de estos bioclastos indica largos

periodos de flotación en cuerpos de agua relativamente importantes. Las Tasmanáceas indican unas condiciones particulares. Estas algas proliferaban en los medios pobres en oxígeno. Su presencia, unida a la ausencia de dinoflagelados, indican una disminución de la salinidad en la zona fótica y un aumento de las condiciones anóxicas (Courtinat, 2000; Tyson, 1993). La abundancia de esporas ornamentadas (Fig. 4 y Fig. 6) indica un medio proximal. Según Reyre (1973), el principal agente de transporte de estos pesados organismos es la hidrodinámica. Estos resultados muestran que en la unidad central de las Sierras Sur-Rifeñas se formó en el Domeriense superior un surco relativamente profundo y confinado, al pie de una plataforma poco profunda correspondiente a la unidad intermedia de las Sierras.

Análisis bioestratigráfico

Domeriense superior. *Las esporas triletes ornamentadas con espinas o escamas se consideran características del Pliensbachiense (Herngreen y Boer, 1974; Boutet, 1981; Schmith, 1987). La especie* K. reissingeri*, la más típica del género, define en el norte de Europa una biozona correspondiente al Rhetiense terminal-Sinemuriense inferior o al Hettangiense.* Neoraistrickia*, conocida en Francia y en Alemania entre el Sinemuriense y el Toarciense superior, está claramente presente en los sedimentos de las Sierras (Fig. 5). Los pólenes bisacados de los géneros* Alisporites *y* Quadraeculina*, raros en estos sedimentos, definen en el dominio sub-boreal una biozona III correspondiente al Liásico. Las grandes formas de* Quatraeculina *se limitan a esta zona, a menudo, con abundancia en el Sinemuriense superior-Toarciense inferior.*

Toarciense inferior. *Su espectro palinológico está marcado por el predominio de palinomorfos marinos: dinoflagelados, acritarcos y raras Tasmanáceas (Fig. 4 y Fig. 6). Los aportes de terrígenos son abundantes, con un claro predominio de Mob.*

Palinomorfos de origen continental. *La asociación del Toarciense inferior (Figs. 5 y 6) está marcada por la aparición de* Ischyosporites variegatus *y del género* Callialasporites*, con* C. dampieri *(Fig. 7A) y* C. trilobatus*. Estos dos taxones han sido identificados en el Toarciense en Francia, en Groenlandia y en el sur de Suecia. En Francia,* l. variegatus *caracteriza una biozona correspondiente al Toarciense.* Callialasporites *define una biozona de valor mundial en el límite Liásico-Dogger y que en Francia caracteriza una zona del Jurásico medio. Este género ha sido identificado en el Toarciense inferior-Aaleniense del NO de Europa. Las asociaciones de los cortes estudiados se caracterizan también por un predominio del género* Classopollis*.*

Palinomorfos de origen marino. *La diversidad de los dinoflagelados del Toarciense inferior (Figs. 5 y 6) es modesta: seis especies. Esta escasa diversidad en el Toarciense inferior es general para el dominio del Tetis. La especie* Luehndea spinosa*, la más abundante en la asociación estudiada, es característica del Toarciense inferior de Inglaterra y constituye un buen marcador del Toarciense inferior de los dominios sub-boreal y del Tetis. Los otros taxones se citan como marcadores importantes del Toarciense inferior de Inglaterra.* N. gracilis *es considerada una especie cosmopolita con gran distribución en las cuencas del hemisferio norte (Van Helden, 1977; Riding* et al.*, 1999). En general, las asociaciones identificadas para el dominio del Tetis son similares a las de las Sierras Sur-Rifeñas, y tienen en común:* Mancodinium semitabulatum*,* N. gracilis*,* L. cirilliae *y* L. spinosa*. Ciertos taxones característicos del dominio del Tetis, en particular el género* Comparadinium*, no han sido reportados en las Sierras. Esto parece estar relacionado con el marco paleogeográfico de este último dominio, que en el Domeriense-Toarciense inferior habría estado comunicado principalmente con el Proto-Atlántico más que con el Tetis, de acuerdo con las faunas de ammonites dominadas por las formas sub-boreales (Amaltheidae y* Hildaites*).*

Conclusión

Los palinomorfos del Domeriense superior, ricos en fitoclastos en forma de agujas, en esporas ornamentadas y en Tasmanáceas, indican un medio de sedimentación proximal, anóxico, y con una considerable profundidad del agua. Los palinomorfos del Toarciense inferior, dominados por organismos marinos (dinoflagelados, Tasmanáceas y acritarcos), indican una apertura del medio. La abundancia en los sedimentos estudiados de partículas leñosas (Mob) y de esporas ornamentadas se explica por la proximidad al litoral y la presencia de un curso importante de agua. Estos resultados concuerdan con los datos de campo: abundancia de madera fósil en los sedimentos jurásicos de la parte sur de la unidad central de las Sierras. El predominio entre los dinoflagelados de formas de origen sub-boreal también concuerda con las asociaciones de fauna de ammonites, ricas en especies sub-boreales. Estos resultados indican, para la cuenca de las Sierras Sur-Rifeñas en el Domeriense y el Toarciense inferior, una mayor comunicación con el Proto-Atlántico que con el Tetis.

Introduction

In contrast to the NW European Sub-Boreal domain where palynological research concerning the Lower Jurassic sequences are numerous (e.g.: Davies, 1983; Schmith, 1987; Srivastava, 1987; Prauss, 1989; Feist-Burkhardt and Wille, 1992; Batten and Kopelhus, 1996; Poulsen, 1996; Bucefalo Palliani and Riding, 1998; Bucefalo Palliani *et al*., 2002; Brittain *et al*., 2010; 2000, 2003, etc.). In the Tethyan realm such research is still very rare: Dodekova (1990), about Bulgaria; Bucefalo Palliani *et al.* (1997), about Hungary; Bucefalo Palliani and Mattioli (1998), about southern Italy; Dino *et al*. (2007), about Portugal. This preliminary investigation is the first palynological study concerning the Middle-Upper Lias transition sequences of the western Tethyan realm's southern margin. Rare palynological studies have been carried out on some Moroccan petroleum exploration wells and the results are in the ONHYM internal well reports. Our study is based on the investigation of two outcrop sections (named SKM and FA), from the central paleogeographic unit of the South Rifian Ridges (Faugères (1978a). These outcrop sections were sampled in the marly deposits, dated by Upper Domerian-Lower Toarcian ammonites (Elmi and Faugères, 1973, 1974; Faugères, 1976, 1978a) and they consequently allow very good stratigraphic correlations. The yielded organic residue from twelve processed samples (four from the Upper Domerian and eight from the Lower Toarcian) have revealed rich lignitic matter, palynofacies and generally well preserved marine-derived microfossils (such as dinoflagellate cysts, acritarchs and Tasmanites) or generally well preserved land-derived microfossils (spores and pollen grains). It has allowed biostratigraphic and paleoenvironmental analysis of the stratigraphic sequences of the South Rifian Ridges during the Upper Domerian-Lower Toarcian.

Studied area

The South Rifian Ridges (or Prerif Ridges) correspond with many Jurassic hills, having a moderate altitude (Fig. 1-2), belonging to the Rif chain foreland in its SW edge. These mountains are wrapped towards the south and the west and they are organized in two outcrop groups (western and eastern Ridges), having an arc-like form, separated by a large depression filled up with Miocene marls. The first group has many, more or less isolated, Jurassic hills between Wadis Beht and Rdom. The second corresponds to the Moulay Idriss Zerhoun massif (in its large sense) and its northern prolongation (the Tselfat Ridge). For the South

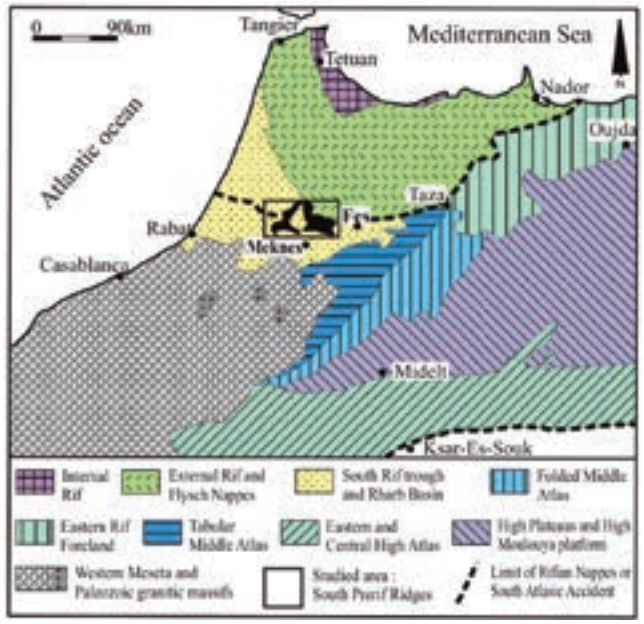

Figure 1. Structural map of North Morocco showing the location of the South Rifian Ridge domain (*In:* Faugères, 1978a), modified.
Figura 1. *Mapa estructural del norte de Marruecos, mostrando la situación del dominio de las Sierras Sur-Rifeñas (modificado de Faugères, 1978a).*

Rifian Ridges Jurassic basement, Faugères (1978a, 1982) has distinguished three lithostratigraphic units, equivalent to three paleogeographic zones (Fig. 2-3):
a peripheral unit, corresponding to the outer area of the basin of the Ridges, having a reduced and incomplete stratigraphic sequence, not younger than the Middle Lias. It shows two formations: the Triassic red shales and sandstones and dolomites and massive limestones of Lower to Middle Lias age;
an intermediate unit, showing, in addition to the two previous unit formations, marls and sandstone alternations with oolitic limestone interbeds of the Toarcian-Middle Bajocian age;
a central unit, corresponding to the centre of the basin of the Jurassic Ridges. This unit forms many outcrops at the north of the Moulay Idriss Zerhoun Accident and is characterized by its marine pelagic deposits of the Middle Lias to Middle Bajocian age.

Location and lithological description of the studied outcrop sections

Two outcrop sections were made in the central-unit marly series:
SKM outcrop section (Fig. 2-4) is located near the Souk of Moulay Idriss Zerhoun, on the right side of

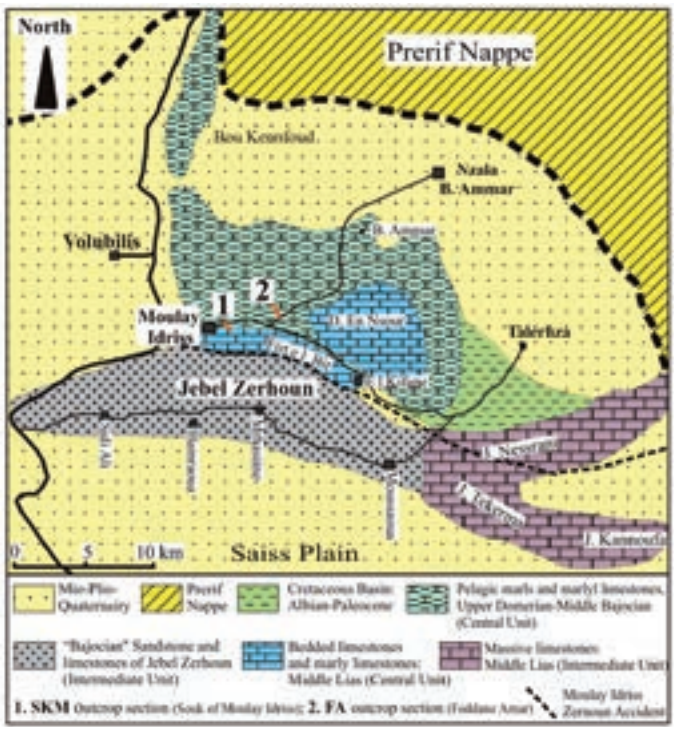

Figure 2. Map of the western South Rifian Ridges, in the Moulay Idriss Zerhoun area, showing the location of the studied outcrop sections SKM (Souk of Moulay Idriss) and FA (Feddane Amar), from the geological maps of Sidi Kacem-scale 1/50 000 (Bendkik, 2004) and Beni Ammar (Chenakeb, 2004).

Figura 2. *Mapa de las Sierras Sur-Rifeñas occidentales, en la zona de Moulay Idriss Zerhoun, mostrando la situación de las secciones estudiadas SKM (Zoco de Moulay Idriss) y FA (Feddane Amar). Tomado de los mapas geológicos a escala 1/50 000 de Sidi Kacem (Bendkik, 2004) y Beni Ammar (Chenakeb, 2004).*

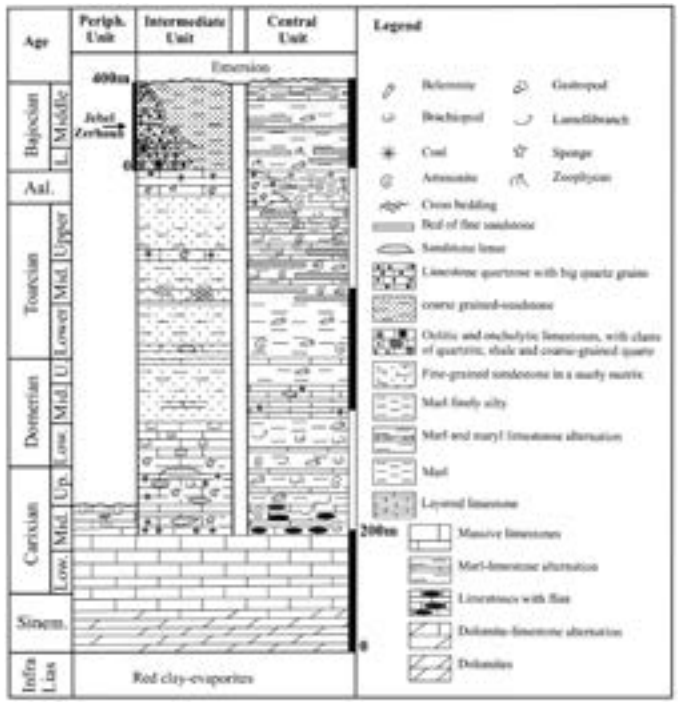

Figure 3. Synthetic logs of the Jurassic sequences of the three paleogeographic units of the South Rifian Ridges (*In*: Boutakiout, 1990, complemented).

Figura 3*. Columna sintética de las secuencias del Jurásico de las tres unidades paleogeográficas de las Sierras Sur-Rifeñas (modificado de Boutakiout, 1990).*

the road going to the Beni Ammar village. It is represented by fine-silty marls corresponding to the Upper Marly Limestones Formation (Faugères, 1978a). The top of this formation, constituted by 1 to 4 m thick grey bioturbated limestones, was dated (Elmi and Faugères, 1973; Faugères, 1976, 1978a) Upper Domerian with rich ammonite fauna: *Pleuroceras solare* (Phillips 1828), *Arieticeras* gr. *algovianum* (Oppel 1862), *Arieticeras ruthenensis* (Reynes 1868), *Tauromeniceras eximium* (Fucuni), *Emaciaticeras* sp. and late Amaltheideae forms: *Amaltheus* gr. *transiens* (Frentzen 1937), *A.* gr. *margaritatus* (Montfort 1808), *Amaltheus* sp. and *Proamaltheus* sp. These non-fossiliferous marls in the studied section, overlay the intermediate layered limestone, assigned to the Lower-Middle Domerian (Faugères, 1978a) and are overlain by grey bioturbated limestone (1 to 4 m thick) showing a yellowish patina, usually containing numerous rostrum of belemnites, clams and ammonites of Late Domerian. It is noteworthy that some micropaleontological studies have also been carried out on the marls of SKM outcrop section and on the bioturbated limestone. These layers were dated using foraminifera and ostracods by Oumalch (1979), Boutakiout (1980, 1990) and Boutakiout *et al.* (1982);

FA outcrop section (Fig. 2-4), situated in Feddane Amar locality 3 km east of the city of Moulay Idriss Zerhoun, by the road going to the Nzala Beni Ammar. It corresponds to the grey marl Formation and to the lower part of the lower sandy marly limestone formation (Faugères, 1978a). These grey marls show some thin limestone beds and were dated (Elmi and Faugères, 1974; Faugères, 1974, 1978a) as Lower Toarcian, by the occurrence of *Dactylioceras semicelatum* (Simpson 1843), *D.* gr. *mirabile* Fucuni 1919, *Bouleiceras* aff. a*rabicum* Arkell 1952*, Bouleiceras* sp.*, Harpoceratoides* cf. *maghrebenses* Guex*, Hildaites* aff. *borealis* (Seebach 1864) and *Hildaites* sp. This outcrop section has also been the subject of recent paleontological works on the belemnites (Sanders *et al.*, 2013) and the ammonites, especially *Dactylioceras*, *Protogramoceras* and *Lioceratoides* belonging to Lower Toarcian (Bardin *et al.*, 2014).

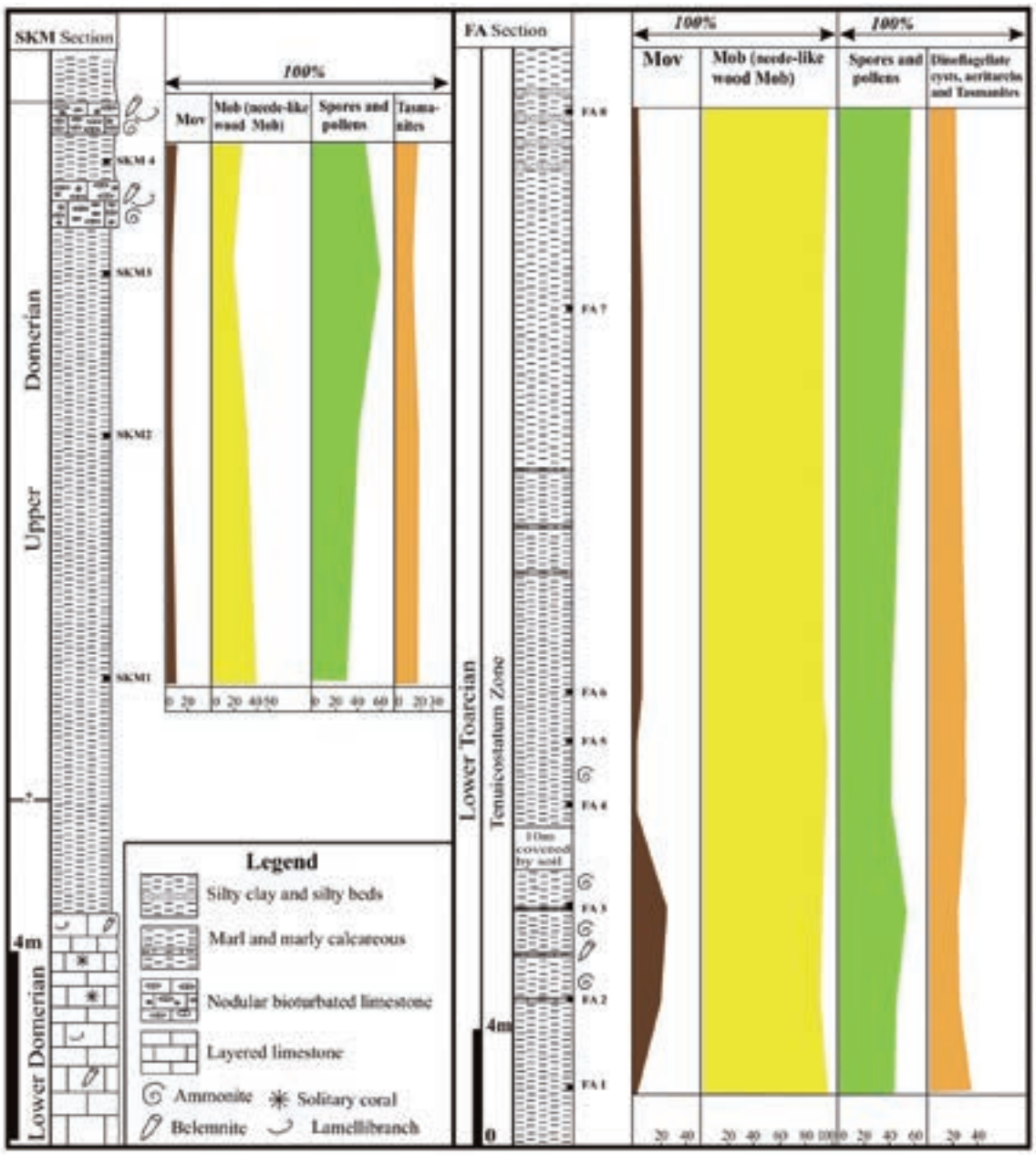

Figure 4. SKM and FA outcrop sections with the relative abundance of the different palynofacies compounds of the Upper Domerian–Lower Toarcian sequence, from the central paleogeographic unit of the South Rifian Ridges.
Figura 4. *Secciones SKM y FA indicando la abundancia relativa de componentes de las diferentes palinofacies de la secuencia del Domeriense superior-Toarciense inferior, en la unidad paleogeográfica central de las Sierras Sur-Rifeñas.*

Methods

Twelve samples were analysed: four collected from Upper Domerian silty marls and eight from Lower Toarcian grey and yellow marls. Before each sampling, a trenching was undertaken to expose a fresh surface of sediment and, so, to avoid superficial contaminations and organic content oxidations by atmospheric agents. For the organic palynomorphs extraction, we used the physico-chemical processing technics, which is performed in the Laboratories of the ONHYM (Office National des Hydrocarbures et des Mines du Maroc) in Rabat. The classical procedure consists in crushing 60 to 80 g of sediment. The obtained powder is digested in concentrated hydrochloric acid HCl (37%), then in hydrofluoric acid HF

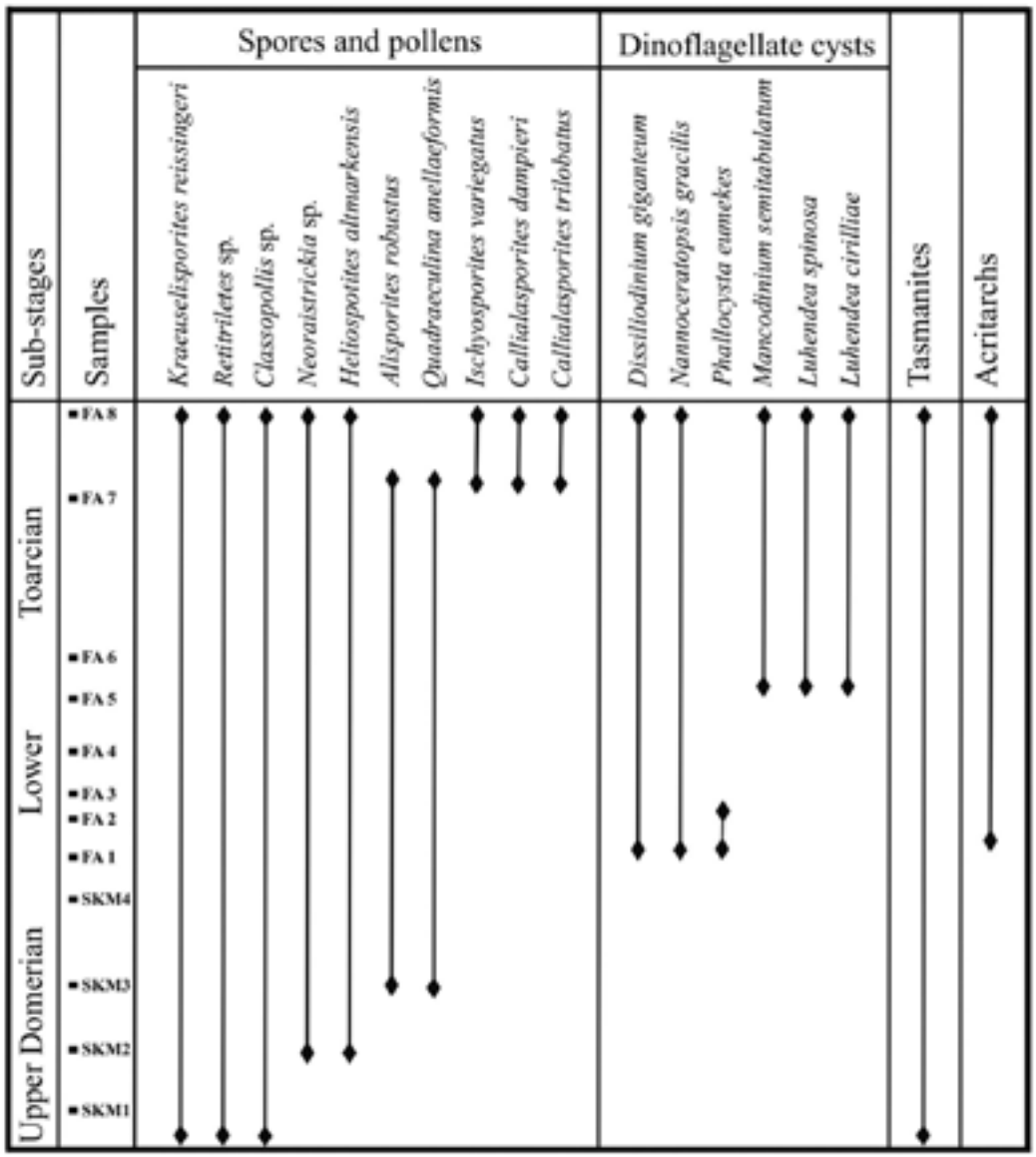

Figure 5. Synthetic table representing the stratigraphic range of the main microfauna and microflora found in the Upper Domerian-Lower Toarcian sediments, from the central paleogeographic unit of the South Rifian Ridges.
Figura 5. *Tabla sintética del rango estratigráfico de la principal microfauna y microflora presente en los sedimentos del Domeriense superior-Toarciense inferior, en la unidad paleogeográfica central de las Sierras Sur-Rifeñas.*

(70%) to eliminate carbonates and silicates respectively each acid digestion procedure was followed by decantation and neutralisation using distilled water. The last stage is the density separation (separation by heavy liquid) of organic content and non-soluble minerals, by flotation on zinc chloride (ZnCl2). A residue drop is mixed with Hydroxyethyl Cellulose (H.E.C. standing for Hydroxyl Ethylene Cellulose), then mounted between slide and cover slip for microscopic observations and analysis of palynofacies and palynomorphs.

Palynological results

Upper Domerian

The organic residue from Upper Domerian samples (SKM outcrop section, Fig. 4) shows two types of organic matter: one of terrestrial origin (Mob), having a brown colour, formed by phytoclasts (20 to 40%) rich in needle-like wood fragments and another type (Mov) with a yellow to brown colour, less abundant (5 to 10 %), formed by cuticles and vegetal cells. Organic

microfossils of terrestrial origin are represented by an assemblage of spores and pollen grains (30 to 60%), containing (Fig. 4; Fig. 6): *Alisporites robustus* Nilson 1958 (Fig. 7J), *Classopollis* sp. (Pflug) Reyre 1970 (Fig. 7I), *Kraeuselisporites reissingeri* (Harris) Morbey 1975 (Fig. 7B), *K. reissingeri* (group) (Fig. 7C-E), *Neoraistrickia* Potonié 1956, *Quadraeculina anellaeformis* Maliavkina 1949 (Fig. 7K), *Retitriletes* sp. (Hammen) Pierce 1961 (Fig. 7G-H). The palynomorphs of marine origin (Fig. 4) are represented by Tasmanites, smooth, spherical organisms, more or less transparent, corresponding to unicellular green algae belonging to the Prasinophyceae group (Praussand Riegel, 1989; Bucefalo Palliani and Riding, 2000; Bucefalo Palliani *et al.*, 2002; Courtinat, 2000). This assemblage is characterized by the absence of dinoflagellate cysts and acritarchs.

Lower Toarcian

The organic residue of Lower Toarcian samples (FA outcrop section, Fig. 4) shows a palynofacies dominated by a Mob-type organic matter, up to 95%, while the Mov-type is less abundant, not more than 5%. In contrast to the Lower Domerian, the organic microfossils of the Lower Toarcian are dominated by marine organisms (45 to 60 %): dinoflagellates and acritarchs, associated with some spores and pollen grains. The spore and pollen assemblages (Fig. 5, Fig. 6) contain, in addition with the species already cited for the Upper Domerian, the following taxa: *Ischyosporites variegatus* (Couper 1958) (Fig. 7F), *Callialasporites trilobatus* (Balme 1957) Dev 1961 and *C. dampieri* (Balme 1957) Dev 1961 (Fig. 7A). Acritarchs are dominated by the genus *Michrystridium* Deflandre 1947. The dinoflagellate assemblages, less abundant and less diversified, contain: *Luehndia spinosa* Mongenroth 1970 (Fig. 7L), *L. cirilliae* Bucefalo Palliani *et al*. 1997 (Fig. 7P), *Mancodinium semitabulatum* (Morgenroth 1970) (Fig. 7M-N), *Nannoceratopsis gracilis* Alberti 1961, *Phallocysta eumekes* Dörhöfer and Davies 1980 and *Dissiliodinium giganteum* (Sarjeant and Stover 1978) (Fig. 7O). The latter species dominates the dinoflagellate assemblages.

Paleoenvironmental and biostratigraphic analysis

The samples collected from Upper Domerian and Lower Toarcian strata have yielded abundant, diversified and relatively well preserved sporopollenic compounds, allowing a reliable paleoenvironmental and biostratigraphical interpretation.

Paleoenvironmental analysis

The organic residue from Upper Domerian deposits (Fig. 4; Fig. 7) yielded a palynofacies dominated by terrestrial forms: spores, pollen grains and phytoclasts (Mob). The occurrence of the latter compounds, regarded as detrital particles, have a spatial distribution particularly dependent on hydrodynamism (Tyson, 1995). It is very important for the paleoenvironmental analysis of the Upper Domerian of the studied area. In fact, the needle-like elongated form of these phytoclasts indicates long period of floating in relatively significant water depths (Courtinat, 2000). The opaque aspect of these phytoclasts indicates anoxic conditions of the sedimentary environment (Tyson, 1993). The occurrence of the Tasmanites, which are the only representatives of the marine palynomorphs, indicates peculiar paleoenvironmental conditions. Their spatial distribution is strictly linked to the physico-chemical conditions of the photic zone, to the water depth and to the climate (Prauss and Riegel, 1989; Bucefalo Palliani *et al.*, 2002). These authors have highlighted that in the oxygen-poor environments, the green algae (*Prasinophyceae ?*), which use reduced nitrates, seem the most adapted algae, able to grow healthily in these environments, in contrast to other types of algae. The authors have interpreted the occurrence of Tasmanites and the absence of the dinoflagellate cysts within marine sediments, as an indication of a decrease in the salinity of the water of the photic zone and an increase in the anoxic conditions (Bucefalo Palliani *et al.*, 2002). The abundance of ornate spores (Fig. 6) in South Rifian Ridge Upper Domerian assemblages also indicates a proximal sedimentary environment. Reyre (1973) found that the main agent responsible for the transport of these heavy organisms is hydrodynamism. This phenomenon of the abundance of ornamented spores in the Pliensbachian facies was highlighted in the Netherlands (Herngreen and Boer, 1974), in SW France (Boutet, 1981) and in Alsace (Schmith, 1987). The latter author qualified it as a Pliensbachian characteristic event. So, the abundance of needle-like, opaque phytoclasts (Fig. 4; Fig. 6), Tasmanites, ornamented spores and the absence of dinoflagellate cysts and acritarchs in the studied sediments indicates that the central paleogeographic unit of the South Rifian Ridges, at least in the area where the sampling was carried out, was a relatively narrow and confined trough, located at the foot of a narrow shallow marine platform corresponding to the intermediate paleogeographic unit of the South Rifian Ridges. This is in accordance to the outcrop data. In fact, the Liassic and Dogger formations show important changes in facies and thickness of the sedimentation on both sides

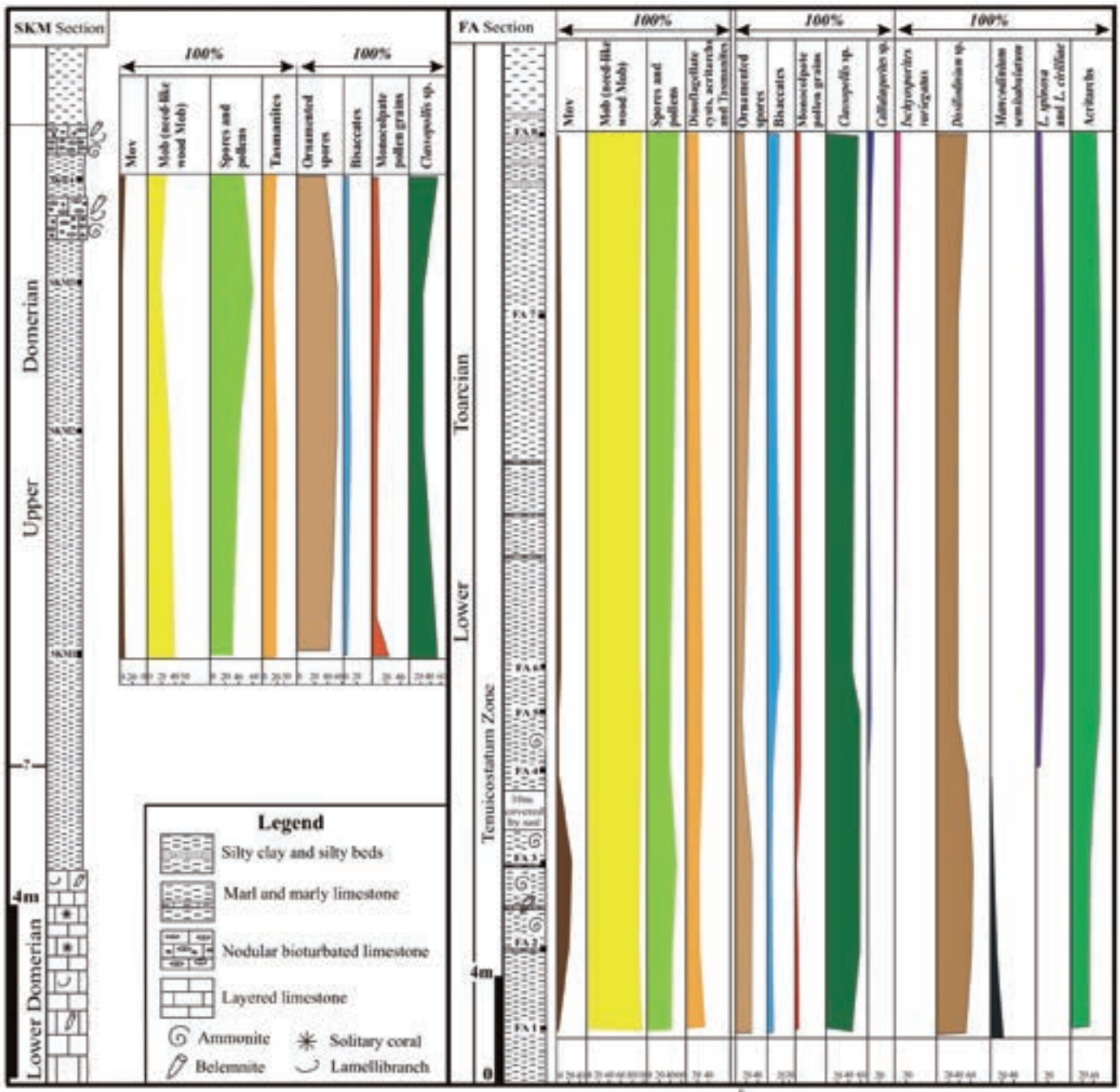

Figure 6. Relative abundance of the different constituents of the palynofacies and the main palynomorphs found in the Upper Domerian-Lower Toarcian interval, from the central paleogeographic unit of the South Rifian Ridges.
Figura 6. *Abundancia relativa de los diferentes constituyentes de las palinofacies y los principales palinomorfos que se encuentran en el intervalo del Domeriense superior-Toarciense inferior, en la unidad paleogeográfica central de las Sierras Sur-Rifeñas.*

of the Moulay Idriss Zerhoun Accident. This accident would have been a major normal fault during the Lias and Dogger times, along which would have occurred the collapse of the central paleogeographic unit of the South Rifian Ridges during the Upper Domerian and Toarcian. On the other hand, the Upper Domerian-Bajocian open up the marine pelagic series of the central paleogeographic unit in the sectors near the Moulay Zerhoun Idriss Accident and exhibit significant continental influences, indicated by the abundance of

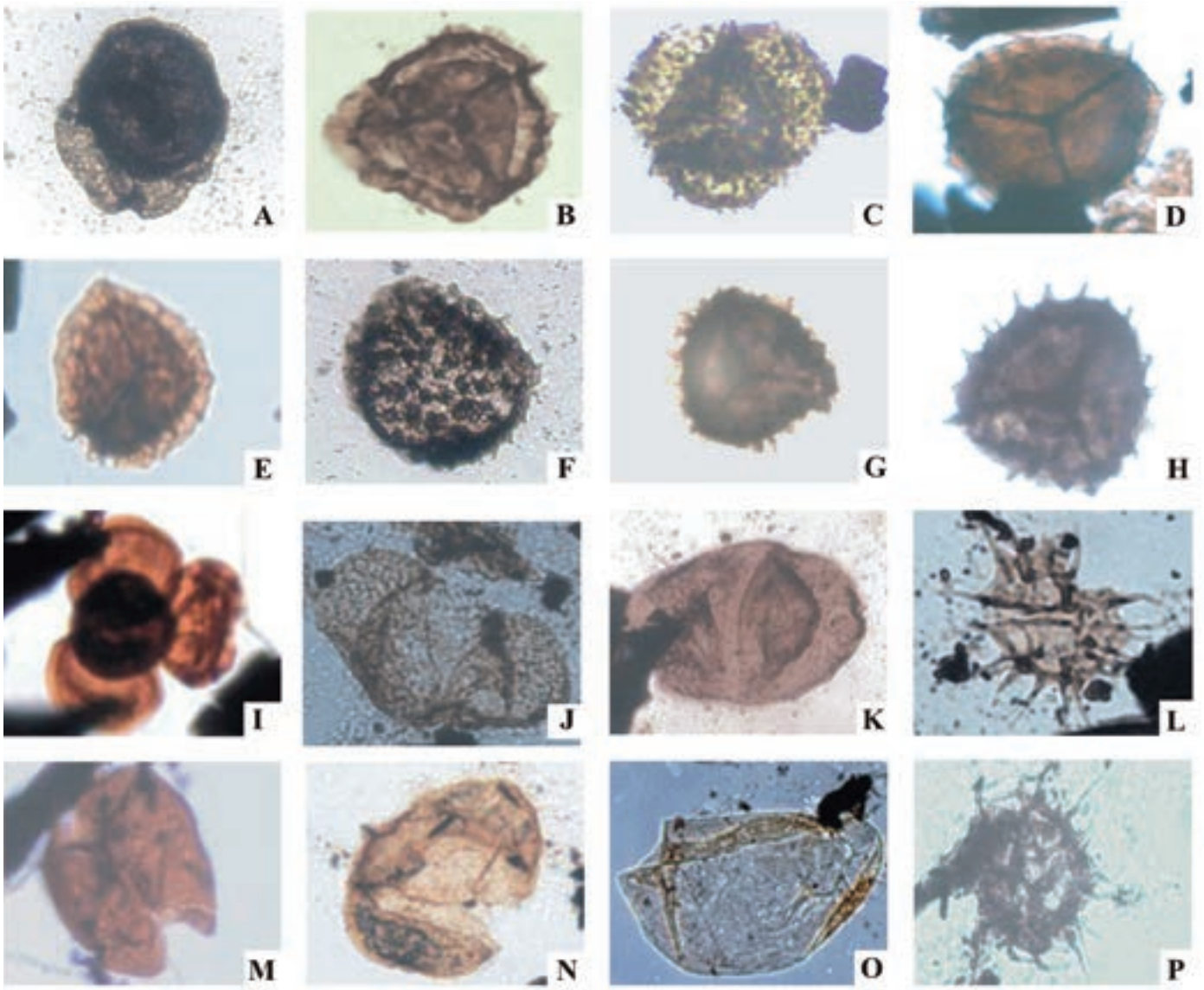

Figure 7. From A to K: spores and pollen grains. A. *Callialasporites dampieri* (Balme) Sukh Dev 1961, FA outcrop section, level FA7, Lower Toarcian. B. *Kraeuselisporites reissingeri* (Harris) Morbey 1975, SKM outcrop section, level SKM3, Upper Domerian. C-E. *Kraeuselisporites reissingeri* (group), SKM outcrop section: C, level SKM: E, level SKM1, Upper Domerian. F. *Ischyosporites variegatus* Couper 1958, SKM outcrop section, level SKM2, Upper Domerian. G-H. *Retitriletes* sp. Pierce 1961: G, FA outcrop section, level FA8, Lower Toarcian: H, SKM outcrop section, level SKM1, Upper Domerian. I. *Classopollis* sp. (Pflug) Reyre 1970, FA outcrop section, level FA5, Lower Toarcian. J. *Alisporites robustus* Nilsson 1958, FA outcrop section, FA5, Lower Toarcian. K. *Quadraeculina anellaeformis* Maliavkina 1949, FA outcrop section, level FA5, Lower Toarcian. From L to O: Dinoflagellate cysts. L. *Luehndea spinosa* (Mongenroth 1970), FA outcrop section, FA5, Lower Toarcian. M-N. *Mancodinium semitabulatum* (Morgenroth 1970), FA outcrop section: M, level FA5: N, level FA8, Lower Toarcian. O. *Dissiliodinium giganteum* (Sarjeant and Stover 1978), FA outcrop section, level FA1, Lower Toarcian. P. *Luehndea cirilliae* Bucefalo Palliani *et al*. 1997, FA outcrop section, level FA5, Lower Toarcian. NB All figures are X 400

Figura 7. *De A a K: esporas y granos de polen. A.* Callialasporites dampieri *(Balme) Sukh Dev 1961, sección FA, tramo FA7, Toarciense inferior. B.* Kraeuselisporites reissingeri *(Harris) Morbey 1975, sección SKM, tramo SKM3, Domeriense superior. C-E.* Kraeuselisporites reissingeri *(grupo), sección SKM: C, tramo SKM: E, tramo SKM1, Domeriense superior. F.* Ischyosporites variegatus *Couper 1958, sección SKM, tramo SKM2, Domeriense superior. G-H.* Retitriletes sp*. Pierce 1961: G, sección FA, tramo FA8, Toarciense inferior: H, sección SKM, tramo SKM1, Domeriense superior. I.* Classopollis sp. *(Pflug) Reyre 1970, sección FA, tramo FA5, Toarciense inferior. J.* Alisporites robustus *Nilsson 1958, sección FA, tramo FA5, Toarciense inferior. K.* Quadraeculina anellaeformis *Maliavkina 1949, sección FA, tramo FA5, Toarciense inferior. De L a O: Quistes de dinoflagelados. L.* Luehndea spinosa *(Mongenroth 1970), sección FA, tramo FA5, Toarciense inferior. M-N.* Mancodinium semitabulatum *(Morgenroth 1970), sección FA: M, tramo FA5: N, tramo FA8, Toarciense inferior. O.* Dissiliodinium giganteum *(Sarjeant y Stover 1978), sección FA, tramo FA1, Toarciense inferior. P.* Luehndea cirilliae *Bucefalo Palliani et al. 1997, sección FA, tramo FA5, Toarciense inferior. Nota: Todas las figuras son X 400.*

fossil-wood fragments and the coarse terrestrial fraction, indicating the proximity of the shoreline and the occurrence of a large fresh water body (fluvial system) coming from the south. This system evolved into a vast delta in the Middle Bajocian (Faugères, 1978a ; Benzaggagh et al. 2106).

Biostratigraphic analysis

Upper Domerian. Schmith (1987) considers that the trilete spores ornamented by spines or bacula are characteristic of the Pliensbachian stage. The *Kraeuselisporites reissingeri,* the most typical species of the genus *Kraeuselisporites*, defines, in northern Europe, the *K. reissingeri* biozone, corresponding to the Late Rhaetian-Lower Sinemurian times, according to Morbey (1978) or to the Hettangian in Alsace (France), according to Schmith (1987). The bisaccate pollen grains of the two genera *Alisporites* and *Quadraeculina*, faintly present in the Upper Domerian assemblages of the South Rifian Ridges, with a percentage less than 10% (Fig. 6), are well represented in the Lower Toarcian samples with a higher amount reaching 25 % (Fig. 6). In the Boreal realm, these two genera define the biozone III of Herngreen and Boer (1974), corresponding to the Lias subsystem. The large forms of *Quatraeculina* are limited to this biozone. In northern Europe, these taxa occur since the Hettangian, with an acme in the Carixian (Morbey, 1975). In France, Boutet (1981) has described them since the Lias, with a higher abundance in the Toarcian, as is the case for the South Rifian Ridges. These large pollen grains occur in NW Europe, from the Upper Sinemurian to the Pliensbachian (Batten and Kopelhus, 1996), with an acme during the Upper Sinemurian-Lower Toarcian interval (Schmith, 1987).

Lower Toarcian. The palynological spectrum of the Lower Toarcian, in contrast to the Upper Domerian, is characterized by the dominance of marine-derived palynomorphs: dinoflagellate cysts, acritarchs and rare Tasmanites (Fig. 4; Fig.6). The terrigenous inputs are very important, with a clear dominance of the Mob.

Terrestrial-derived palynomorphs. The Lower Toarcian assemblage (Fig. 5; Fig. 6) is characterized by the appearance of the species *Ischyosporites variegatus* and the genus *Callialasporites;* represented by the species *C. dampieri* and *C. trilobatus.* These two taxa were recognized in the Toarcian in France (Schmith, 1987), in Greenland (Pedersen and Lund, 1980) and in the south of Sweden (Guy, 1971). Saad (1963), Couper (1958) and Ashraf (1977) found them since the Dogger, respectively in Sinai (Egypt), England, Iran and Afghanistan. In NW Europe, *Ischyosporites variegates* was cited in the Upper Pliensbachian (Batten and Kopelhus, 1996). In France, this species characterises the *I. variegates* biozone corresponding to the Toarcian (Schmith, 1987). The genus *Callialasporites*, with the species *C. dampieri* defines a global biozone, characteristic of the Lias-Dogger boundary (Schmith, 1987). In France, this genus characterises the *Callialasporites* biozone (Schmith, 1987), where the base is represented at the Lias-Dogger boundary. For northern Europe, this genus characterises a biozone corresponding to the Upper Toarcian (Morbey, 1978). The genus *Callialasporites* was also reported in NW Europe since the Aalenian (Batten and Kupelhus, 1996) or since the Lower Toarcian (Srivastava, 1987). Sporopollenic assemblages of the studied outcrops are characterized by ornamented spores, but also by a large dominance of the pollen genus *Classopollis* (or *Corollina)*, especially in the Lower Toarcian sediments (Fig. 6), with amounts reaching 60 %. This pollen group is the most abundant group of palynological microfossils of the Mesozoic times with a worldwide scale. It represents a fossil family of the Conifera, very different from whole living families (Reyre, 1973).

Marine origin palynomorphs. Lower Toarcian dinoflagellate cyst diversity of the studied outcrop section is rather low, since only six species have been found (Fig. 5; Fig. 6). This phenomenon is common in the Tethyan realm (Bucefalo Palliani *et al*., 2002). In the Sub-Boreal domain of NW Europe, many studies have been undertaken on the Lower Jurassic palynology, using dinoflagellate cysts. In England, Riding and Walton (1991), Riding and Thomas (1992) underlined a great richness and an important diversity of the dinoflagellates in the *Hildoceras bifrons* zone of the Lower Toarcian. *L. spinosa,* the most abundant species within the assemblage of the studied outcrop section, is characteristic of the Middle Toarcian of England (Riding and Thomas, 1992) and it never exceeds the *Tenuicostatum* zone (base of the Toarcian) in NW Scotland (Riding and Walton, 1991). This species together, with *L. cirilliae,* seems to be a good marker of the Tethyan Lower Toarcian and Sub-Boreal realms. *Luehndea cirilliae* was reported in the SW of Hungary from the interval *P. spinatum* zone-*H. falciferum* zone. The other Lower Toarcian taxa of the South Rifian Ridges were also considered as important biostratigraphic markers of the Lower Toarcian of England (Riding and Thomas, 1992). *N. gracilis* is usually cited from the Upper Pliensbachian to Bajocian in England (Bucefalo Palliani and Riding, 2003) and in NW Europe (Feist-Burkhardt and Wille, 1992; Bucefalo Palliani and Riding, 2000; Poulsen,

1996; Davies, 1983). This species is present in the South Rifian Ridges from the Lower Toarcian to Middle Bajocian (work in progress), but it is always rare. This stratigraphic distribution is concordant with that given by Van Helden (1977), Riding *et al.* (1999). These authors consider *N. gracilis* as being a cosmopolitan species, having a large distribution, in all the whole basins of the Northern Hemisphere. The Lower Toarcian assemblage of the South Rifian Ridges appear to be very similar to those reported in England in synchronous stratigraphic levels, though some English species, such as *Parvocysta nasuta* Bjaerke 1980 and *Susadinium scrofoides* Dörhöfer and Davies 1980 are not encountered in the studied outcrop sections. In Germany, the dinocyst assemblages cited for the Lower Toarcian (Prauss, 1989; Feist-burkhardt and Wille, 1992) are similar to those of the South Rifian Ridges, with the absence of some taxa such as: *Valveodinium ormatum* Morgenroth 1970 and *N. triceras* Drugg 1978 in the South Rifian Ridges. In the Tethyan realm, where only few studies on the Lower Jurassic dinoflagellate cysts have been undertaken, the assemblages cited by Dino *et al*. (2007), Bucefalo Palliani and Mattioli (1998), Schmitt (1987) and Dodekova (1990) are similar to the Lower Toarcian ones of the South Rifian Ridges, with *Mancodinium semitabulatum*, *N. gracilis* and *L. spinosa* as common dinoflagellate taxa. In fact, the predominance in the South Rifian Ridges of Lower Toarcian sediments of the dinoflagellate cysts having a sub-boreal origin and the scarcity or the absence of some taxa of the Tethyan realm, is well concordant with Upper Domerian-Lower Toarcian ammonite assemblages of the South Rifian Ridges. Elmi and Faugères (1973), Faugères (1976) have underlined a massive, but belated arrival of the Amaltheidae in the basin of the South Rifian Ridges, in the Late Middle Domerian and mainly in the Upper Domerian. These NW European macrofauna, are well-known and are abundant in Portugal since the base of the Middle Domerian and they are rare in the Betic and Iberian chains in Spain and completely absent in the Moroccan High Atlas. Faugères (1978b), Faugères and Mouterde (1979) suggest that since the Upper Domerian, the South Rifian Ridges basin was widely open towards the Proto-Atlantic which was expanding towards the south, allowing the arrival of cold-water faunas of the northern European basins in the basin of the South Rifian Ridges. At that time, communications between the Tethys (or Mesogean) ocean and the Proto-Atlantic furrow were not yet well-established. The Iberian plate was forming a barrier between the two basins. According to the latter authors, this paleogeographic scheme lasted during the Lower Toarcian, with mixed faunal assemblage, Tethyan and NW European ones, particularly *Hildaites* aff. *borealis.* It is only from the Middle Toarcian, that the South Rifian Ridge marine faunal assemblages, especially ammonites, will be dominated by Mesogean taxa, indicating a large communication between the Proto-Atlantic and the Mesogean basins.

Conclusions

The investigated stratigraphic sequences (Upper Domerian-Lower Toarcian) have yielded palynofacies which are dominated by continental influx (Mob). In the silty marls of the Upper Domerian, the needle-like phytoclasts, associated to a significant amount of ornamented spores of Tasmanites, indicate an anoxic, proximal sedimentary environment, with an important water depth. In the Lower Toarcian marls, the palynofacies is dominated by marine organisms (dinoflagellate cysts, acritarchs, Tasmanites). The abundance of acritarchs, particularly the genus *Michrystridium*, indicates a marine environment (Courtinat, 1998), in relation to the Middle Liassic carbonate platform dislocation and a global transgression during the lower Toarcian (Haq *et al*., 1988). In the studied sediments, the abundance of the lignitic particles (Mob) and ornamented spores may be related to the proximity of the shoreline and the presence of a large fresh water body (fluvial system). These results are in accordance with the outcrop data. The open marine successions of the Upper Domerian-Middle Bajocian of the meridional part of the central paleogeographic unit of the South Rifian Ridges show important terrestrial influences (abundance of fossil wood debris and the coarse terrigenous fraction), indicating the proximity of the coast and the presence of a large fresh water body. The predominance of sub-boreal-derived taxa in the dinoflagellate assemblages regarding tethyan taxa is also in accordance with the ammonite fauna assemblages. These are rich in sub-boreal-derived species. These paleontological results reveal, for the South Rifian Ridges domain, a large communication with the Proto-Atlantic (in expansion towards the south), rather than with the Tethys, during the Domerian and Lower Toarcian.

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