

Environmental parameters of a coral assemblage from the Akerchi Formation (Carboniferous), Adarouch Area, central Morocco

Parámetros ambientales de una asociación de corales de la Formación Akerchi (Carbonífero), Área de Adarouch, Marruecos central

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Abstract

Rich assemblages of rugose corals occur in the Tizra, Akerchi and Idmarrach formations (Mississippian) near El-Hajeb City. The Akerchi Formation, approximately 140 m thick, is divided into two members. The upper part of the lower member contains a biostrome 2 to 5 m thick, composed mainly of rugose corals and gigantoproductid brachiopods embedded in marly limestone. Its local thickness increases from southwest to northeast in an outcrop extending for more than one kilometre.

The Akerchi biostrome is mostly composed of rugose corals. Brachiopods, bryozoans, porifera (chaetetids, sponges), and molluscs are conspicuous elements of the biostrome, but none of them constitutes a significant component. Other common fossil taxa in thin sections are foraminifers, algae and cyanobacteria, ostracods, trilobites and echinoderms. The coral assemblage in the biostrome is regarded as a paleocommunity, because the biostrome is not composed of distinct coral bearing beds in different time slices, but rather, it is a mass of corals which in many instances show their original relationships and continuous colonial growth. The assemblage is diverse, including 12 genera and 20 species.

Micro- and macrofacies analyses of corals and surrounding rock allowed some environmental inferences: a high level of energy is suggested by the degree of fragmentation of branches in fasciculate colonies and other features of the rocks. However, the energy was not high enough to destroy the colonies, and the presence of abundant micrite indicates that the energy level was discontinuous. Other environmental factors inferred from paleoecological and taphonomical evidences are shallow water with normal marine

salinity and a hard substrate provided by quick cementation of oolite bar and by abundant bioclasts. Massive coral colonies and gigantoproductids are attached directly to the oolite bar which in turn provided a hard substrate for attachment of fasciculate corals that are dominant in the biostrome.

Keywords: Carboniferous, Viséan, corals, palaeoecology, biostrome, Morocco.

Resumen

Las formaciones Tizra, Akerchi e Idmarrach (Mississippiense) que afloran cerca de El-Hajeb City en Marruecos central han proporcionado diversas y abundantes asociaciones de corales rugosos. La Formación Akerchi, de unos 140 metros de espesor se divide en dos miembros. Los últimos metros del miembro inferior están constituidos por un biostromo de 2 a 5 metros de espesor compuesto principalmente por corales rugosos y braquiópodos gigantoproductidos englobados en caliza margosa, que se extiende más de 1 kilómetro. Además de los rugosos y braquiópodos, otros componentes notables son briozoos, poríferos (esponjas y chaetétidos) y moluscos, pero ninguno de ellos representa porcentajes importantes. Otros componentes fósiles frecuentes en lámina delgada son foraminíferos, algas y cianobacterias, ostrácodos, trilobites y equinodermos. La asociación del biostromo puede considerarse como una paleocomunidad, porque el biostromo no está compuesto por capas bien diferenciadas, sino que se trata de una masa de corales que en muchos casos muestran sus relaciones originales de crecimiento. La asociación de corales es diversa e incluye 12 géneros y 20 especies.

Análisis macro y microfaciales de los corales y de las rocas que los rodean permiten algunas interpretaciones ambientales: un alto nivel de energía es sugerido por el grado de fragmentación de las ramas en corales fasciculados y otras características de las rocas. Sin embargo, la energía no era suficiente para fragmentar las colonias y la abundancia de micrita indica que el alto nivel de energía no era constante, permitiendo la decantación. Otros factores ambientales que se deducen de evidencias paleoecológicas y taxonómicas son profundidad escasa, salinidad normal y substrato duro provisto por una rápida cementación y por abundantes bioclastos. Colonias de corales masivos colonizaron una barra oolítica y proporcionaron el substrato duro necesario para la fijación de corales fasciculados que dominan en el biostromo.

Palabras clave: Carbonífero, Viseense, corales, paleoecología, biostromo, Marruecos..

1. Introduction

The present study is focused on the Adarouch Area (Figure 1), located in the northeastern part of the Variscan Massif of central Morocco which has experienced complex tectonic deformation, notably thrusting. The Paleozoic rocks from Adarouch form part of the zone of transition between the Western and the Eastern Mesetas (Berkhli, 1999) named "Azrou-Khenifra Region" by Piqué (1979). Mississippian rocks from the Adarouch Area (northeast central Morocco) crop out along a vast area south of the El-Hajeb City (Fig. 1). Palaeozoic rocks in that region show a NE-SW orientation and they are bound by Mesozoic rocks (Triassic and Jurassic). The Palaeozoic outcrops comprise Ordovician, Devonian, Mississippian and Pennsylvanian rocks. The Mississippian rocks have been subdivided in four lithostratigraphic units (Fig. 2): from the base to the top, they are the Oued Amhars Formation, the Tizra Formation, the Mouarhaz Formation and the Akerchi Formation (Berkhli 1999). To the East, an additional unit crops out, the Idmarrach Formation. These formations include Viséan and Serpukhovian rocks, dated using foraminifers and calcareous algae (Berkhli, 1999; Berkhli and Vachard, 2001; Berkhli *et al.*, 2001). The micropaleontological data suggest that the Serpukhovian is only present in the upper part of the Akerchi and Idmarrach formations.

Rich assemblages of rugose corals occur in the Tizra, Akerchi and Idmarrach formations (Said *et al.*, 2007; Said, 2005). The objective of this paper is to analyse the palaeoecological parameters of a complex assemblage with an exceptional exposure characterized by its high diversity and situated in the lower part of the Akerchi Formation. The analyses of this assemblage include: 1) a palaeoecologic study, following the protocol proposed by Vuillemin (1990) and Somerville and Rodríguez (2007). 2) a taphonomical study of rugose corals (Rodríguez, 2004). They will be combined with an analysis of microfacies for the identification of the environmental factors that affected the development of the rugose corals following methodologies proposed by Bosence and Allison (1995) and Flügel (2004). We assume that taphonomical processes begin before corals are buried or died and so, the boundary between taphonomy and palaeoecology is not clear. It is specially marked in reefal environments. Because of this reason we will include most observations in a unique chapter of palaeoecologic analysis.

2. The Akerchi Formation

The Akerchi Formation is approximately 140 m thick and is subdivided into two members (AK1 and AK2, Berkhli 1999, Berkhli and Vachard, 2001) of a readily

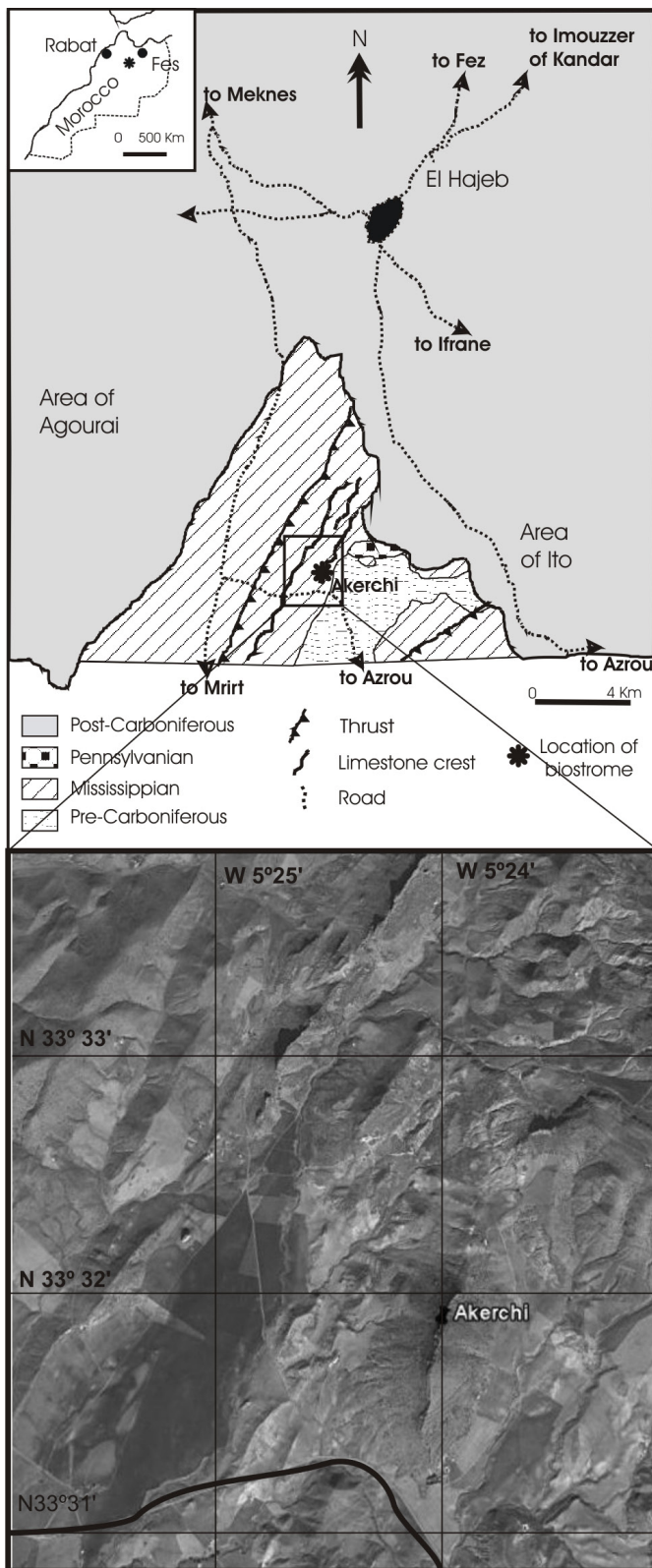


Fig. 1.- Location of the Akerchi outcrops..

Fig. 1.- Mapa de localización de los afloramientos de Akerchi.

distinct lithological content. The entire formation produces a ridge that is elevated about 200 meters above the surrounding plateau (Fig. 3a).

The lower member is only 16 meters thick (AK1; Fig. 2b). The lower beds are composed of channelized polygenic conglomerates, and bioclastic limestones. The bioclastic limestones pass progressively to oolitic limestones that are well bedded at the base, but massive at the top (Figs. 2, 3b). Above, a biostrome 2 to 5 meters thick is recognized, composed of masses of rugose corals and gigantoproductid brachiopods embedded in marly limestones (Fig. 2).

The upper member (AK2) starts with 22 metres of calcareous sandstones with cross stratification followed by a succession of 100 metres of thin-bedded laminated limestones alternated with sandstone beds is located over the sandstones (Fig. 3c). This AK2 member has been attributed to the Serpukhovian by Berkli and Vachard (2001); however, the precise dating of this member needs further studies, because the coral assemblage at the base is typically Brigantian, which highlights that at least part of the member might be Viséan in age. A precise biostratigraphy of foraminifers and algae from Akerchi Formation is shown in Cózar *et al.* (2008).

3. The Akerchi biostrome

The Akerchi biostrome is located in the transitional beds between the lower and upper members (AK1/AK2) by Berkli and Vachard (2001), but is here considered as the top of the lower member. It is 2 to 5 m thick (3 m in average). Its local thickness increases from the Southwest to the Northeast and it can be followed for more than a kilometre.

The biostrome is mostly composed of rugose corals (about 50% of the rock), but many other phyla occur there. Brachiopods, bryozoans, porifera (chaetetids, sponges), and molluscs are conspicuous elements of the biostrome, but none of them reaches a significant percentage of the rock. Rugose corals are progressively substituted by layers of gigantoproductids (Fig. 4a) in the southwest border of the biostrome outcrop. Coral colonies disappear first from the lower part of the bed and the coral biostrome persists only in the upper part where they grew on gigantoproductid shells. Other common fossil taxa in thin sections are: foraminifers, algae and cyanobacteria, ostracods, trilobites, and crinoids. Bioclasts are usually not oriented.

Sediment around the colonies varies from the base to the top of the biostrome. Ooids are common in the lower part of the biostrome, but they rarely reach significant percentages in the upper part, where fragments of corals constitute high percentages. The level of cementation in the intercolonial spaces varies from the lower to the upper part; it is quite high at the base, but micrite is abun-

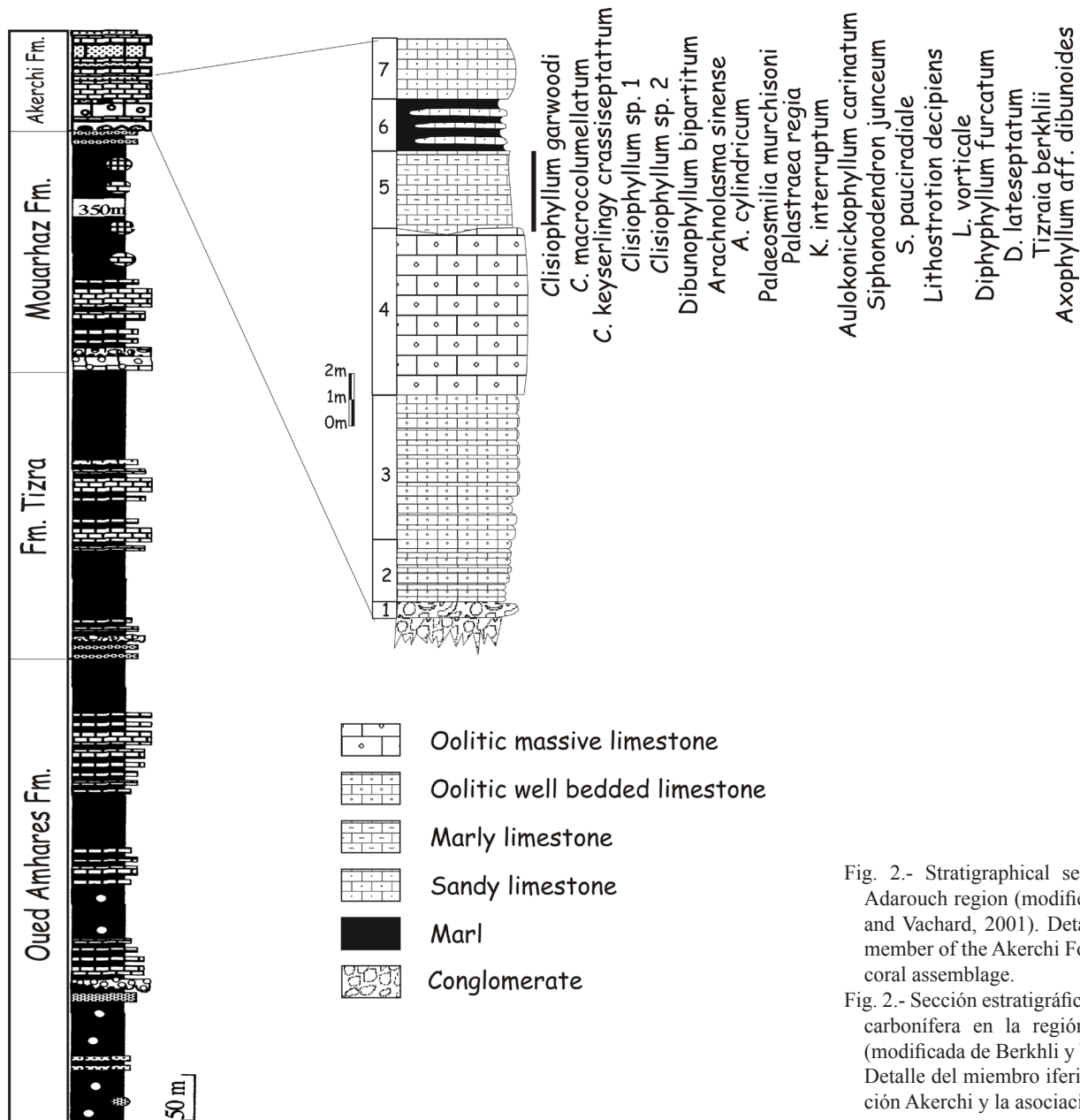


Fig. 2.- Stratigraphical section from the Adarouch region (modified from Berkhli and Vachard, 2001). Detail of the lower member of the Akerchi Formation and its coral assemblage.

Fig. 2.- Sección estratigráfica de la sucesión carbonífera en la región de Adarouch (modificada de Berkhli y Vachard, 2001). Detalle del miembro inferior de la Formación Akerchi y la asociación de corales.

dant around the corals in most areas of the biostrome. Textures are typically homogeneous, but micropeloidal and laminate textures have been recorded in the upper part of the biostrome.

4. The coral assemblage

The coral assemblage of the biostrome is regarded as a paleocommunity, because the biostrome is not composed of distinct coral bearing beds from different time slices, but rather a mass of corals. In most cases their original relationships and a continuous growth of the colonies are evident and show fragmentation, but are not transported far in most instances. Thus, the high percentage of com-

ponents in growth position, and the conspicuous short remobilisation of some components define the Akerchi biostrome as an autoparabiostrome following the definition of Kershaw (1994).

Corals began to grow on the surface of oolitic bars, because the specimens at the base of the biostrome are lying directly on the irregular upper surface of the massive oolitic bar (Fig. 4b). Corals are numerous, reaching more than 50% of the rock as an average, and the assemblage is diverse; 12 genera and 20 species, including rugose and tabulate corals, have been recorded: 2 massive genera (*Lithostroton* Fleming 1828, *Palastraea* McCoy 1851), 4 fasciculate genera (*Siphonodendron* McCoy 1849, *Diphyphyllum* Lonsdale 1845, *Tizraia* Said and Rodríguez

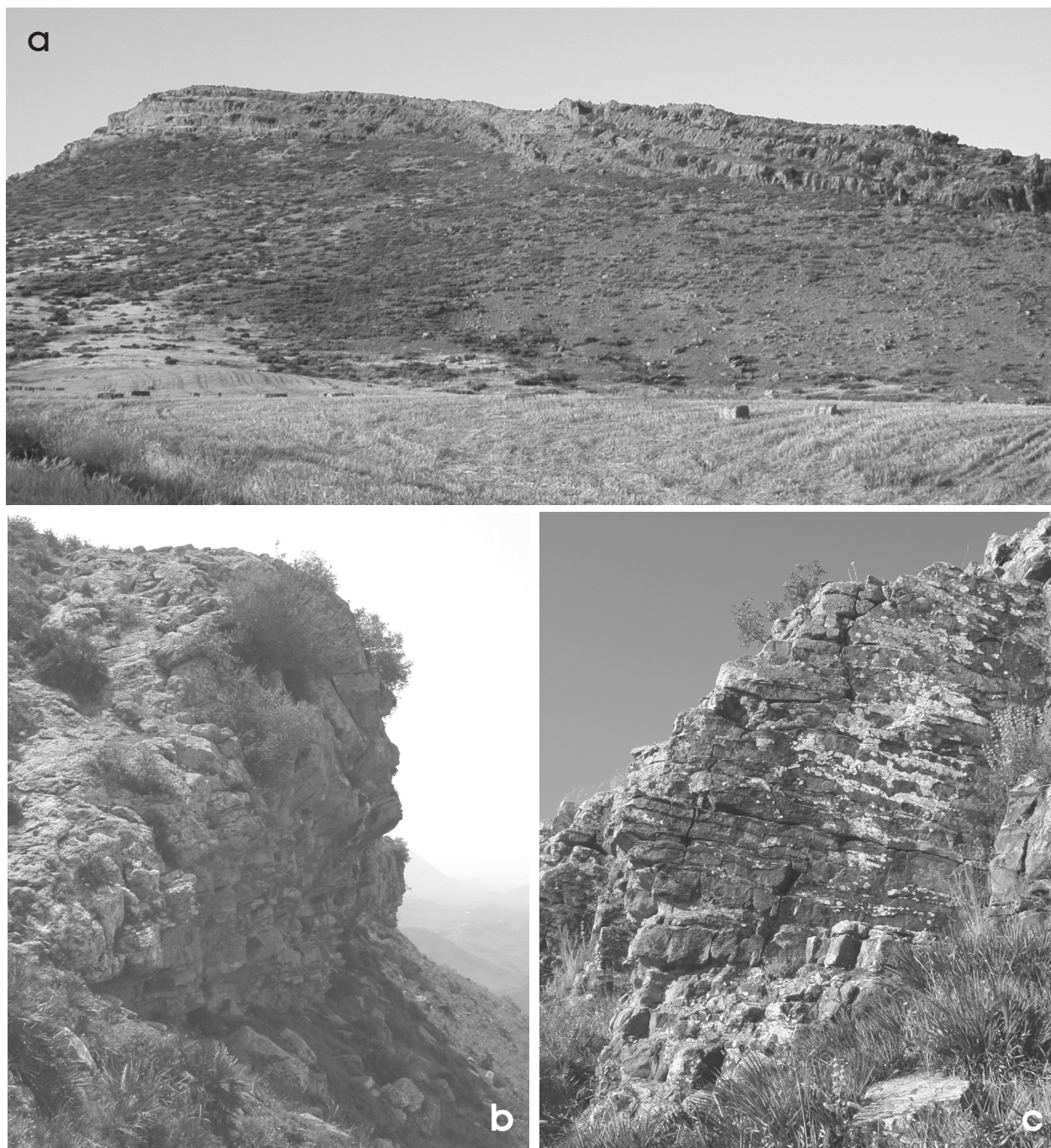


Fig. 3.- Field aspect of the Akerchi Formation. a.- General view of the Akerchi ridge. b.- Cliff formed by well bedded and massive oolite limestone at the lower member of Akerchi Formation. c.- Well bedded limestone at the upper member of the Akerchi Formation.

Fig. 3.- Aspectos de campo de la Formación Akerchi. a.- Vista general de la sierra de Akerchi. b.- Crestón formado por las calizas oolíticas (masivas y tableadas) del miembro inferior de la Formación Akerchi. c.- Calizas tableadas del miembro superior de la Formación Akerchi..

2007, *Syringopora* Goldfuss 1826) and 6 solitary genera (*Palaeosmia* Milne-Edwards and Haime 1848, *Dibunophyllum* Thomson and Nicholson 1876, *Arachnolasma* Grabau 1922, *Clisiophyllum* Dana 1846, *Koninckophyllum* Thomson and Nicholson 1876 and *Axophyllum* Milne-Edwards and Haime 1850). Some of them, such

as *Siphonodendron*, *Lithostrotion* or *Clisiophyllum* are represented by several species. Most corals in the biostrome core are phaceloid (*Siphonodendron*, *Tizraia*, *Diphyphyllum*, and *Syringopora*) but massive corals are common in the lower part of the biostrome and solitary corals, usually of large size, occur everywhere between

the colonies. The whole coral assemblage is listed in Figure 2. Lower parts of the biostrome, close to the oolite bar show dominance of *Lithostrotion vorticale*. Nevertheless, the dominant species in the biostrome as a whole is *Siphonodendron junceum* (Fleming, 1828), specially in the upper parts, where it reaches up to 80% of the rock (Fig. 4c), because in addition to the large, densely packed colonies, thousands of branch fragments of this species fill the spaces between the corals (Fig. 4d). Colonies of this species reach a large size, up to 3 metres in diameter and 1.5 metres high, but other phaceloid species show smaller size.

5. Paleocological observations

Massive colonies of *Palastraea* and *Lithostrotion* are often directly growing on the oolitic bar top (Fig. 4b). Phaceloid corals are commonly in life position and frequently attached to other colonial corals or gigantoproductid brachiopods. They do not show evidence of significant transport (e.g. sorting, overturning, etc.), but they show frequent partial fragmentations and many of them are tilted on their side. There is no dominant direction in the distribution of fallen colonies. The dominance of *Siphonodendron junceum* increases to the top and to-

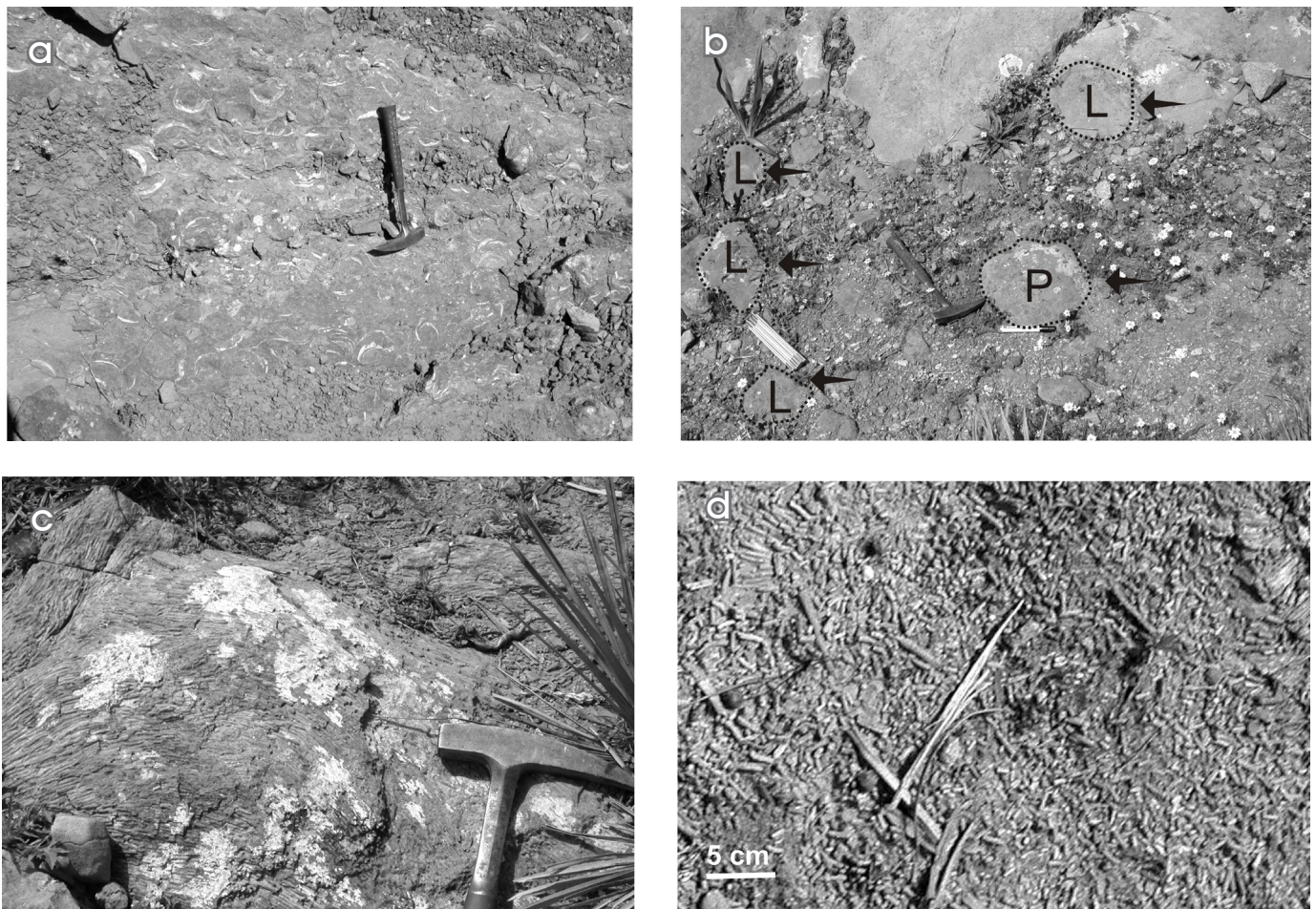


Fig. 4.- Field features of the Akerchi biostrome. a.- Gigantoproductids form the biostrome southwards from the coral area. The scale-hammer is 32 cm in length. b.- Colonies of massive corals (P = *Palastraea*, L = *Lithostrotion*) lying directly on massive oolitic limestones (pale grey rock in the upper part of the picture). The marked colonies are located in life position. L = *Lithostrotion* colonies, P = *Palastraea* colony. The dark spots around the colonies are fragments of branches of *Siphonodendron junceum*. The scale-hammer is 32 cm in length. c.- Large colonies of *Siphonodendron junceum* with hundreds of thin branches in each colony. The hammer head is 18 cm in length. d.- Detail of broken branches of *Siphonodendron junceum* covering the spaces intercolonies in the biostrome.

Fig. 4.- Características de campo del biostromo de Akerchi. a.- Gigantoprodúctidos del biostromo al sur de la zona coralina. El martillo de escala tiene unos 32 cm de longitud. B.- Colonias de corales masivos (P = *Palastraea*, L = *Lithostrotion*), directamente apoyadas sobre las calizas masivas oolíticas. Las colonias marcadas están en posición de crecimiento. Las manchas oscuras alrededor de las colonias son fragmentos de ramas de *Siphonodendron junceum*. El martillo de escala tiene unos 32 cm de longitud. C.- Grandes colonias de *Siphonodendron junceum* con cientos de ramas en cada colonia. La cabeza del martillo tiene 18 cm de longitud. D.- Detalle de ramas rotas de *Siphonodendron junceum* que cubren los espacios entre colonias en el biostromo.

wards the North. Solitary corals, brachiopods and molluscs are irregularly distributed in the intercolonial space.

Examples of interrelation of corals and other taxa are common in the biostrome. Solitary corals show common attachment processes, such as talons and rootlets. The colonial corals from the Akerchi biostrome are typically attached to gigantoproductids and other corals, but molluscs (mainly gastropods), bryozoans and chaetetids are also used as hard substrate for attachment. The walls of corallites in *phaceloid* corals also show common expansions for stabilization (Fig. 5a). Chaetetids show notable interrelation activity with solitary rugose corals. The latter attached commonly on the surface of chaetetids that subsequently grew around the corals producing skeletal anomalies on them (Fig. 5b). On the other hand, incrustations on the coral walls are abundant. The most common encrusters are cyanobacteria (*Girvanella*), serpulid worms (*Spirorbis*), problematic algae (*Claracrusta*) and foraminifers (*Tetrataxis*, Fig. 5c). Bryozoans and chaetetids are also common encrusters on the coral walls and less frequently on the coral calices. Micritic crusts that are probably produced by cyanobacteria or similar microbes commonly surround corals.

Skeletal anomalies related to environment stress are common. Fragmentations that are subsequently repaired (Fig. 5d), as well as changes in growth direction, show that in many cases corals survived to the environmental disturbances. Deformations in the coral walls and unusual growth forms show that corals were affected by mechanic or biochemical activity of other taxa (Fig. 5e,f). Some *Lithostrotion* specimens temporarily change their cerioid habit to phaceloid. Those changes are periodical in some instances reflecting that periods of inadequate conditions for the growth of those corals were common in that environment. Internal anomalies, which are probably due to pathologies, occur in some corals. Some colonies of *Siphonodendron junceum* show anomalies on the wall in the form of small cavities open to the external surface. Anomalies in the normal development of tabulae are common in many specimens of both, colonial and solitary corals (Fig. 5g).

Borings are scarce in the colonies; only some microborings produced by endolithic algae and mesoscopic borings similar to the genus *Gastrochaenolites* have been recorded (Fig. 5h). Microborings are more common on the coral walls than on the calices, indicating that most of them were produced during the life of the coral.

6. Discussion

The coral assemblage from the Akerchi biostrome is comparable to the RCA4B association of Somerville and

Rodríguez (2007). The RCA4B is characterized by the dominance of the genera *Siphonodendron* and *Lithostrotion* and the relationships with oolitic bars that mark shallow water. The absence of the genus *Actinocyathus* is the main difference of the Akerchi assemblage with similar coral associations in Ireland (Somerville, 1997), Great Britain (Mitchel, 1989) or Belgium (Poty, 1981). That genus is also absent in similar assemblages from Spain (Sierra del Castillo, Rodríguez *et al.*, 2002, 2007); consequently its absence is probably related to biogeographical parameters (perhaps latitude), but not to ecological factors. Additionally, the genus *Tizraia* is common in the Akerchi biostrome. This genus has this far only been recorded in the Brigantian and Serpukhovian from Morocco and Spain, and it is common in Tizra and Akerchi formations.

Some environmental factors have been identified from the previous observations:

6.1. Hydrodynamic energy

The spatial organisation of corals and other bioclasts provides information on several aspects related to environmental hydrodynamic energy (Plumley *et al.*, 1962; Bosence and Allison, 1995; Flügel, 2004). A high level of energy is suggested by the degree of fragmentation of branches in fasciculate colonies, their distribution in the intercolonial spaces and the presence of tilted colonies. Moreover, the presence of common processes of attachment points towards moderate or high energy. It could be due also to long period of exposition before burial and these factors could work together in this way. However, the energy was not enough to transport most colonies, not even those of small size. In addition, the presence of abundant micrite indicates that such level of energy was not permanent, but there were long time spans of low energy that allowed the calcareous mud in suspension to precipitate. The inter-particle cementation is very low in the Akerchi biostrome, except in zones close to the oolitic bar, which proves that the high-energy periods were usually short and mainly restricted to the areas near the shoals. The presence of common repaired skeletal anomalies also indicates an alternation of long quiet periods and short high-energy-events. The periods of high energy finished abruptly because bioclasts in the intercolonial spaces do not show orientation or sorting (Scoffin, 1993). The main direction of waves or current has not been identified because the surface of the strata is not observable.

All the features show that masses of corals and brachiopods grew together in a favourable environment. Oolitic bars provided protection for the coral assemblage against the normal waves, creating a quite quiet environment

during long time periods. This scenario was interrupted during storms that produced some disturbances in the development of coral colonies.

6.2. Salinity

The presence of corals and brachiopods and the high biodiversity indicate that the environment was marine with normal salinity (about 36-40 ppm) (Fürsich, 1993). The large oolitic bar partly protected the environment where the corals grew, but did not isolated it from open sea.

6.3. Depth and accommodation space

Presence of common cyanobacteria indicates that the corals lived in the photic zone (Liebau, 1980, 1984; Madi et al., 1996; Aguirre et al., 2000). Moreover, the presence of common ooids in many points of the biostrome suggests common wave activity and corals growing directly on the oolitic bar point to a direct relationship with that environment. Consequently, we consider that the biostrome developed in shallow waters.

On the other hand, the dense packing of the corallites in the colonies and the common interaction between colonies and between different kinds of skeletal organisms indicate that the organic productivity was very high, producing problems of competition for space during the growth of the different components of the biostrome. The vertical growth was relatively restricted because the fasciculate colonies did not reach large vertical sizes and they did not grow one on top of another, thus indicating a strict control of the sea water surface (Rodríguez et al., 1994).

6.4. Oxygenation

The abundance of colonial corals and bioclasts and the high specific biodiversity indicate that the oxygenation level of the water was also high (Allison et al., in Bosence and Allison, 1995). Even if the environment had long periods of moderate to low energy, the periodical events of high energy and the good communication with open sea produced a well-oxygenated environment.

6.5. Temperature

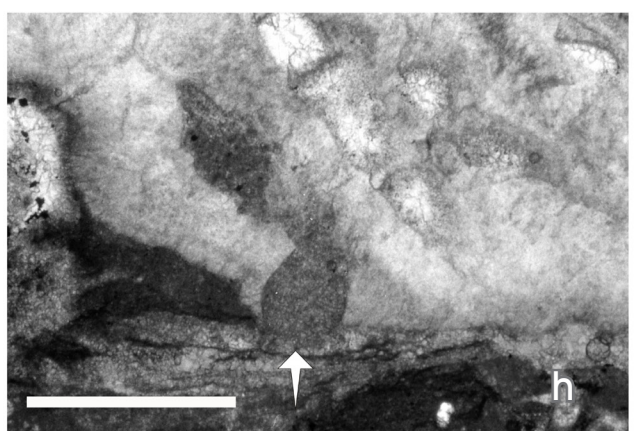
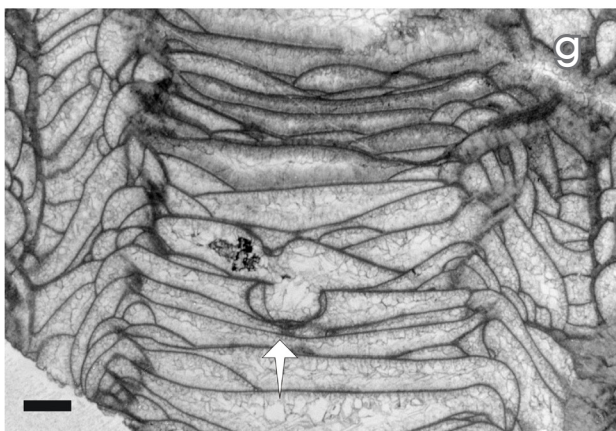
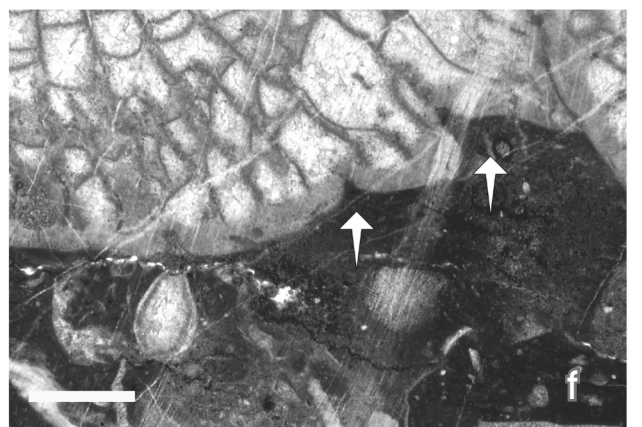
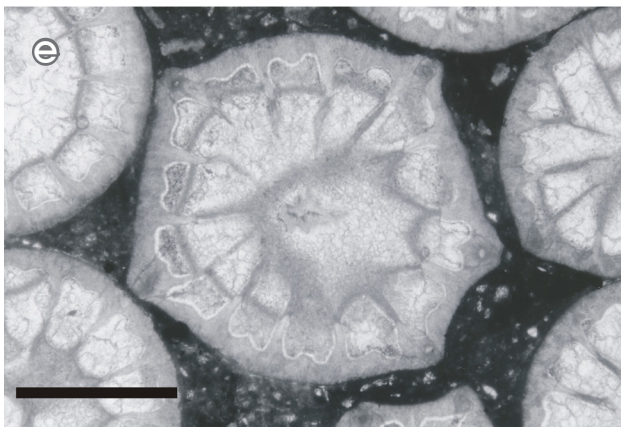
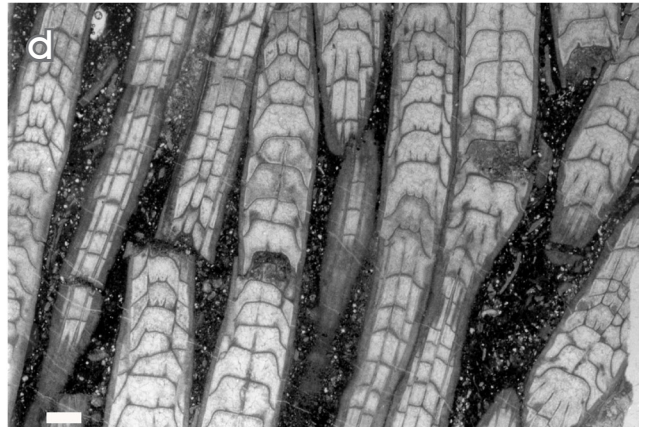
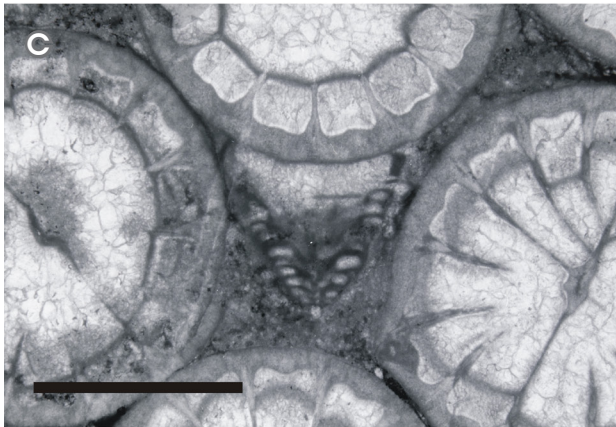
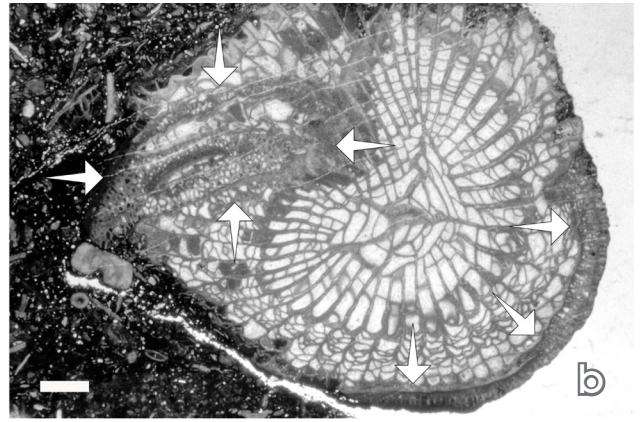
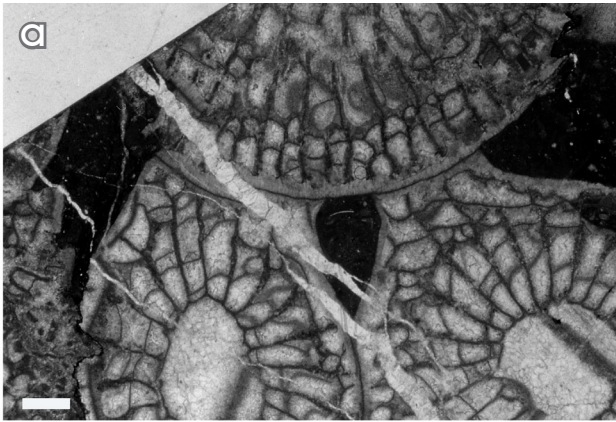
No precise data on the water temperature is recognized, but all features of the fossil assemblage suggest a temperate to warm environment; abundance of corals and extensive growth of colonial organisms is typical of tropical seas in recent environments and we can expect similar situation in the Upper Palaeozoic. It agrees with the supposed tropical position of the area during the Viséan, as reported in most Carboniferous paleogeographic maps (Scotese and McKerrow, 1990; Vai, 2003).

6.6. Substrate

The types of bioclasts and microfacies features provide valuable information for the identification of substrate (Brett, 1988; Copper, 1992; Goldring in Bosence and Allison, 1995). Some massive colonies and many gigantoproductids are attached directly to the oolite bar that shows grainstone texture. A quick cementation of the oolite bar probably provided a hard substrate for coral attachment. Subsequently, most phaceloid colonies are attached on gigantoproductids and on massive coral colonies. Solitary corals and other colonial taxa (bryozoans,

Fig. 5.- Thin sections from the Akerchi biostrome. a.- AKE1/1-46. Adaptation of corallites shape in *Tizraia* to the reduced space in a densely packed colony developing lateral expansions. b.- AKE1/1-33. Inter-growing of a chaetetid (arrows) and a young solitary rugose coral (*Arachnolasma*). The rugose coral attached to the chaetetid, which continued its growth, in turn affecting the development of the coral. The coral skeleton shows considerable anomalies that did not impede its growth. Later, another chaetetid colonised the coral wall (right lower). c.- AKE1/1-1. *Tetrataxis* attached to a branch of *Siphonodendron junceum*. Note the dense packing of the colony. d.- AKE1/1-1. Longitudinal section of *Siphonodendron junceum* showing several fractures. e.- AKE1/1-1. Corallites of *Siphonodendron junceum* showing skeletal anomalies possibly used for attachment to neighbouring corallites. f.- AKE1/1-46. Conspicuous skeletal anomalies in a coral wall (arrows). g.- AKE1/1-27. Anomalies in the tabulae of *Tizraia* (arrow). h.- AKE1/1-25. *Gastrochaenolites*-like boring in the wall of a rugose coral. All scales = 1 mm.

Fig. 5.- Detalles en lamina delgada del biostromo de Akerchi. a.- AKE1/1-46. Adaptación de la forma de los coralitos en *Tizraia* al espacio de crecimiento en una colonia muy densa que desarrolla expansiones laterales. b.- AKE1/1-33. Intercrecimiento de un chaetétido (flechas) y un coral rugoso solitario juvenil (*Arachnolasma*). El coral rugoso se fijó al chaetétido, que continuó su crecimiento, afectando al desarrollo del coral. Éste muestra notables anomalías en su desarrollo que no impidieron su crecimiento. Posteriormente, otro chaetétido colonizó la muralla del coral (derecha abajo). c.- AKE1/1-1. *Tetrataxis* incrustante fijado a una rama de *Siphonodendron junceum*. Nótese el denso empaquetamiento de la colonia. d.- AKE1/1-1. Sección longitudinal de *Siphonodendron junceum* mostrando varias fracturas. e.- AKE1/1-1. Coralitos de *Siphonodendron junceum* que muestran anomalías esqueléticas, posiblemente usadas para fijación a coralitos vecinos. f.- AKE1/1-46. Anomalías esqueléticas importantes en la muralla de un coral (flechas). g.- AKE1/1-27. Anomalías en las tábulae de *Tizraia* (flecha). h.- AKE1/1-25. Perforaciones del tipo *Gastrochaenolites* en la muralla de un coral rugoso. Todas las escalas = 1 mm.



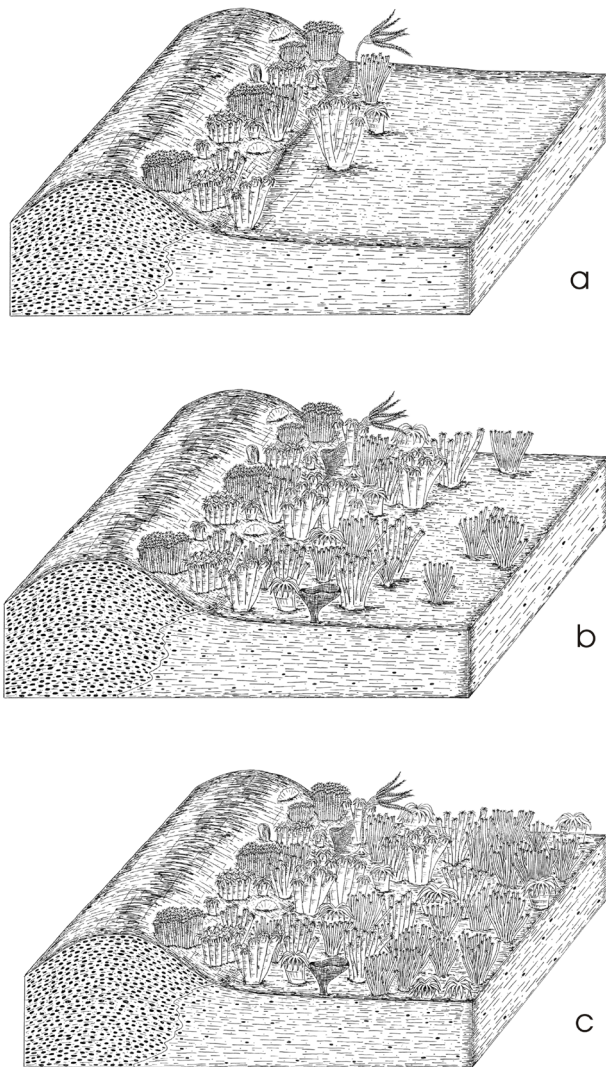


Fig. 6.- Evolution of the Akerchi community. a.- Coral colonies colonize the leeward side of an oolite shoal. Massive colonies are dominant. b.- The community colonizes wider areas and fasciculate colonies become dominant. A high biodiversity characterizes this phase. c.- *Siphonodendron junceum* becomes highly dominant during the phase of maximum extension of the community.

Fig. 6.- Evolución de la comunidad de Akerchi. a.- Colonias de coral colonizando el lado de sotavento de una barra oolítica. Las colonias masivas son dominantes. b.- La comunidad coloniza más amplias zonas y las colonias fasciculadas comienzan a dominar la asociación. Una alta biodiversidad caracteriza esta fase. c.- *Siphonodendron junceum* llega a dominar totalmente la comunidad durante la fase de máxima extensión de la misma.

chaetetids) are attached to coral or shell fragments. No extensive cementation is recorded in the biostrome and the sediment around the corals is mainly micritic. Consequently, the substrate during the development of the biostrome was probably soft or at least firm, but the abundance of skeletal fragments provided enough material for the attachment of colonies. The small size of these parti-

cles acting as hard substrate caused some colonies to tilt over during high energy events.

6.7. Sedimentation rate

The paucity of borings suggests two hypotheses: 1) the activity of borers was limited or 2) the sedimentation rate was very high, covering quickly the surfaces of corals. The presence of abundant encrustations and micritic crusts that need a considerable time-span for developing, indicates that the first hypothesis is more reliable. The abundant organic production and the competition for space also support that hypothesis.

All these environmental factors show a complete picture of the environment where the biostrome was developed (Fig. 6). The existence of a system of calcareous shoals allowed the leeward attachment of some small cerioid and aphroid colonies of rugose corals and gigantoproductids. The skeletal substrate provided by the massive corals and gigantoproductids, and the protected environment provided by the shoals allowed the subsequent development of a rich community dominated by fasciculate corals. The maximum expansion of this community was marked by a strong dominance of the species *Siphonodendron junceum*. The protection of the shoals produced a quiet environment but did not impede a good communication with the open sea and a periodical disruption by storms.

7. Comparison

Development of coral biostromes is common in the Viséan from western Palaeotethys. Many examples have been described in Belgium, British Islands, France and Spain. (Poty, 1981; Rodríguez *et al.*, 1994; Aretz, 2002; Somerville and Rodríguez, 2007; Somerville *et al.*, 2007). Their lateral extension varies from some tens of meters to several kilometres and diversity is usually high. However, the main components of those biostromes are usually few fasciculate species of the genus *Siphonodendron* (mainly *S. junceum*, *S. pauciradiale* and/or *S. martini*). The assemblage from Akerchi fit well with the coral association RCA4 of Somerville and Rodríguez (2007). Moreover, oolitic bars are commonly related to that type of biostrome, usually providing protection against strong waves.

Coral assemblage from Akerchi belong clearly to the Western Paleotethys subprovince (Fedorowski, 1981). It contains the most common colonial and solitary genera in this subprovince such as *Siphonodendron*, *Lithostroction*, *Diphyphyllum*, *Palaeostraea*, *Clisiophyllum*, *Dibun-*

Genera	Poland	British Islands	Belgium	Armorica	Sierra Morena	Akerchi	Sahara
<i>Actinocyathus</i>		•	•				
<i>Amygdalophyllum</i>			•		•		•
<i>Arachnolasma</i>	•				•	•	•
<i>Aulina</i>		•	•				•
<i>Auloclisia</i>		•			•	•	•
<i>Aulokoninckophyllum</i>			•		•	•	•
<i>Aulophyllum</i>	•	•	•	•	•		•
<i>Axoclisia</i>					•	•	•
<i>Axophyllum</i>	•	•	•	•	•	•	•
<i>Bothrophyllum</i>	•		•				•
<i>Caninia</i>	•	•	•	•	•	•	•
<i>Caninophyllum</i>		•	•	•	•		•
<i>Carruthersella</i>	•						•
<i>Clisiophyllum</i>	•	•	•	•	•	•	•
<i>Corwenia</i>	•	•			•		
<i>Dibunophyllum</i>	•	•	•	•	•	•	•
<i>Diphyphyllum</i>	•	•	•	•		•	•
<i>Dorlodotia</i>		•	•				
<i>Gangamophyllum</i>	•		•				•
<i>Haploplasma</i>	•	•	•	•	•		•
<i>Koninckophyllum</i>	•	•	•	•	•		•
<i>Lithostrotion</i>	•	•	•	•	•	•	•
<i>Lonsdaleia</i>	•	•	•				
<i>Melanophyllum</i>	•		•				
<i>Nemistium</i>		•	•				
<i>Neoclisiophyllum</i>					•		
<i>Orionastraea</i>	•	•					
<i>Palaeosmilia</i>	•	•	•	•	•	•	•
<i>Palastraea</i>	•	•		•	•	•	•
<i>Pareynia</i>			•				•
<i>Pseudozaphrentoides</i>		•	•		•	•	•
<i>Siphonodendron</i>	•	•	•	•	•	•	•
<i>Siphonophyllia</i>	•	•	•	•	•	•	•
<i>Slimoniphyllum</i>	•	•					
<i>Solenodendron</i>		•	•	•	•		•
<i>Tizraia</i>						•	

Table 1.- Generic comparison between assemblages from Akerchi and the main coral areas in the Western Palaeotethys Province.
 Tabla 1.- Comparación genérica entre las asociaciones de Akerchi y las principales áreas con corales en la provincia del Paleotethys Occidental.

phyllum, *Palaeosmilia* and others (Table 1). However, it shows some peculiarities: Coral diversity is higher than in any previous described example from northern areas. It shows absence of some genera that are common in similar biostromes of the same age in British Islands and in Belgium (*Actinocyathus*, *Dorlodotia*, *Nemistium*, *Lonsdaleia*, *Orionastraea*). Such absence have been observed also in similar biostromes from Spain and could be due to palaeogeographic factors related to the location of the Moroccan outcrops in the southern rand of the

Western Palaeotethys, in different latitude than the European assemblages. On the contrary, diphyphyllid corals (*Diphyphyllum*, *Tizraia*) that are absent in the Spanish upper Viséan examples, are common in the Akerchi biostrome, as well as in the British instances. The absence of diphyphyllid corals in Spain seems to be related with partial isolation of the Spanish basins.

Some other differences are related to the abundance of some of the common taxa, mainly expressed at family and subfamily level between the southern areas (Sierra

Morena and Akerchi). So, the axophyllidae are abundant in Sierra Morena (Rodríguez *et al.*, 2007) and they are diverse but scarce in Akerchi. On the contrary, the clisiophyllinae and dibunophyllinae are more abundant in Akerchi. They are small differences probably due to the biogeographic (and consequently also latitudinal) distance between those areas. More detailed comparisons will be possible when some other areas in Morocco will be studied.

8. Conclusion

The biostrome located in the top of the lower member of the Akerchi Formation constitutes a good example of ancient ecosystem because of its high diversity and its excellent exposures. The biostrome developed in shallow platform partly protected by oolitic bars, but without marks of restriction, because waters were well oxygenated and salinity was marine normal. The hydrodynamic energy was mostly low to moderate, but the influence of waves was strong, at least periodically, because fragmentation is considerable in the biostrome. The environment was optimal for the development of very diverse skeletal organisms because the diversity is very high and the competition for space indicates a high organic productivity. Nevertheless, the organisms living there had some problems in their growth, probably due to the strong competition, because skeletal anomalies are common.

An ecological succession has been observed. Small massive colonies and gigantoproductids produced first colonisation on the leeward side of the oolitic bars. Subsequently a highly diverse community dominated by fasciculate rugose corals flourished in the protected zone.

The coral assemblage from Akerchi biostrome shows many similarities with equivalent examples from Europe, but also significant differences that were caused by the palaeogeographic location of the Moroccan biostrome.

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