

SEASONAL RHYTHMITES FROM A LOWER PLEISTOCENE LAKE IN NORTHEASTERN SPAIN

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ABSTRACT

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Chemical, sedimentological, ostracod and palynological data were obtained in order to investigate the rhythmic alternation of grey and beige silty layers, with the occasional presence of sandy layers, from a small lacustrine deposit in Catalonia.

The deposit was formed in a shallow meromictic and slightly saline lake. Occasional floods from a nearby river brought in detritic material.

The alternation of the silty layers is seasonal: pollen and ostracods demonstrate that the beige layers were deposited during spring and the grey layers towards the end of spring and after it, until the next spring.

Graded bedding, bioturbation structures and iron nodules found in the deposit are also examined for further information on the formation of the deposit.

Pollen suggests an age for the deposit ranging between the Senezian I (probably representing the Waalian Stage, after Elhaï, 1969) and the Granada Interstadial (which is believed to correspond to the Holsteinian Stage by Florschütz et al., 1971).

INTRODUCTION

On the left flank of the River Fluvia valley, and at the junction of the Maia and Segaro rivers (Dosquers municipality in the Gerona Province — Fig.1), there occurs a deposit consisting mainly of alternating beige and grey silty layers. This deposit, which extends over an area of 100 m² and is 2.5 m thick, was previously quarried near an old mill (= Moli Vell). The top part of the outcrop was eroded away and is now covered with pebbles and loam. A hundred metres upstream of the Maia River, a second deposit

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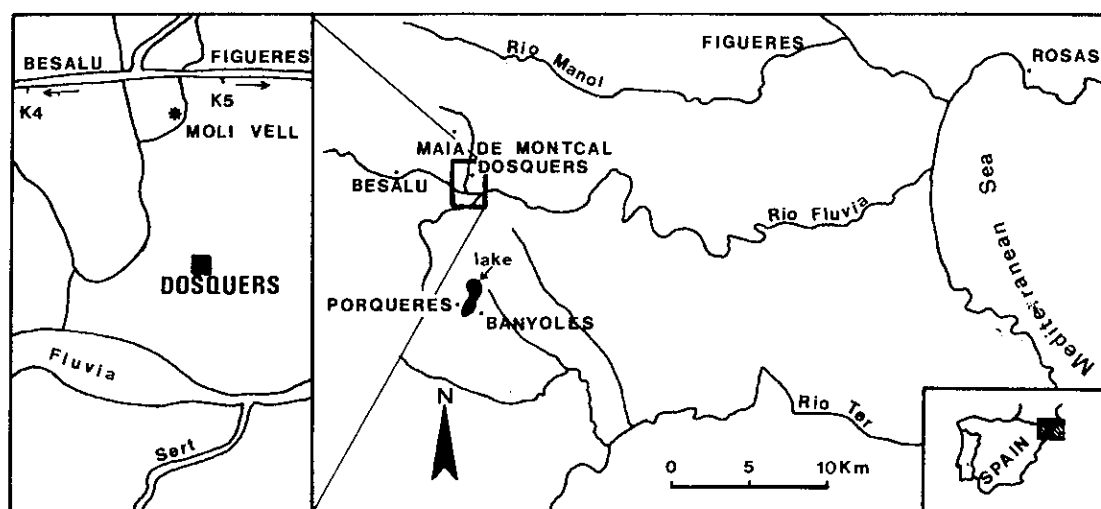


Fig.1. Map showing the locality of the Moli Vell deposit.

occurs, which is wider and thicker and stratigraphically younger. It is also characterized by silty laminations of alternating colours but these are less distinct. This deposit is not studied here.

In the local stratigraphical context, the base Moli Vell deposit could be a facies equivalent of the Incarcal Formation, the topmost part of which was dated as Donau-Günz by De Villalta and Vincente (1972). Above the two previously mentioned deposits with alternating layers, a pebbly layer of Mindel age is found (Sole Sabaris, 1957).

This project was undertaken in order to investigate the differences between the alternating beige and grey layers and to find the reason for the distinct change in colour between the two layers. The environment of deposition, in the stratigraphical context, was also studied. For that purpose, samples were collected in order to analyse their chemical composition, sediment, ostracod and pollen content.

COMPARATIVE STUDIES

Sedimentology and chemical composition

Sedimentology

A profile, 1.73 m thick, was studied in detail at the Moli Vell quarry. The samples were collected in zinc boxes (30 cm x 4 cm x 4 cm) placed vertically one on top of another from the base of the deposit. The samples, kept in these boxes, were then examined in the laboratory. The description of this profile is summarized in Fig.2; 68 levels were distinguished and they are numbered on that figure. Some of these levels were sampled and examined for their palynological, ostracod, mineralogical and chemical contents and those samples bear the numbers of these levels.

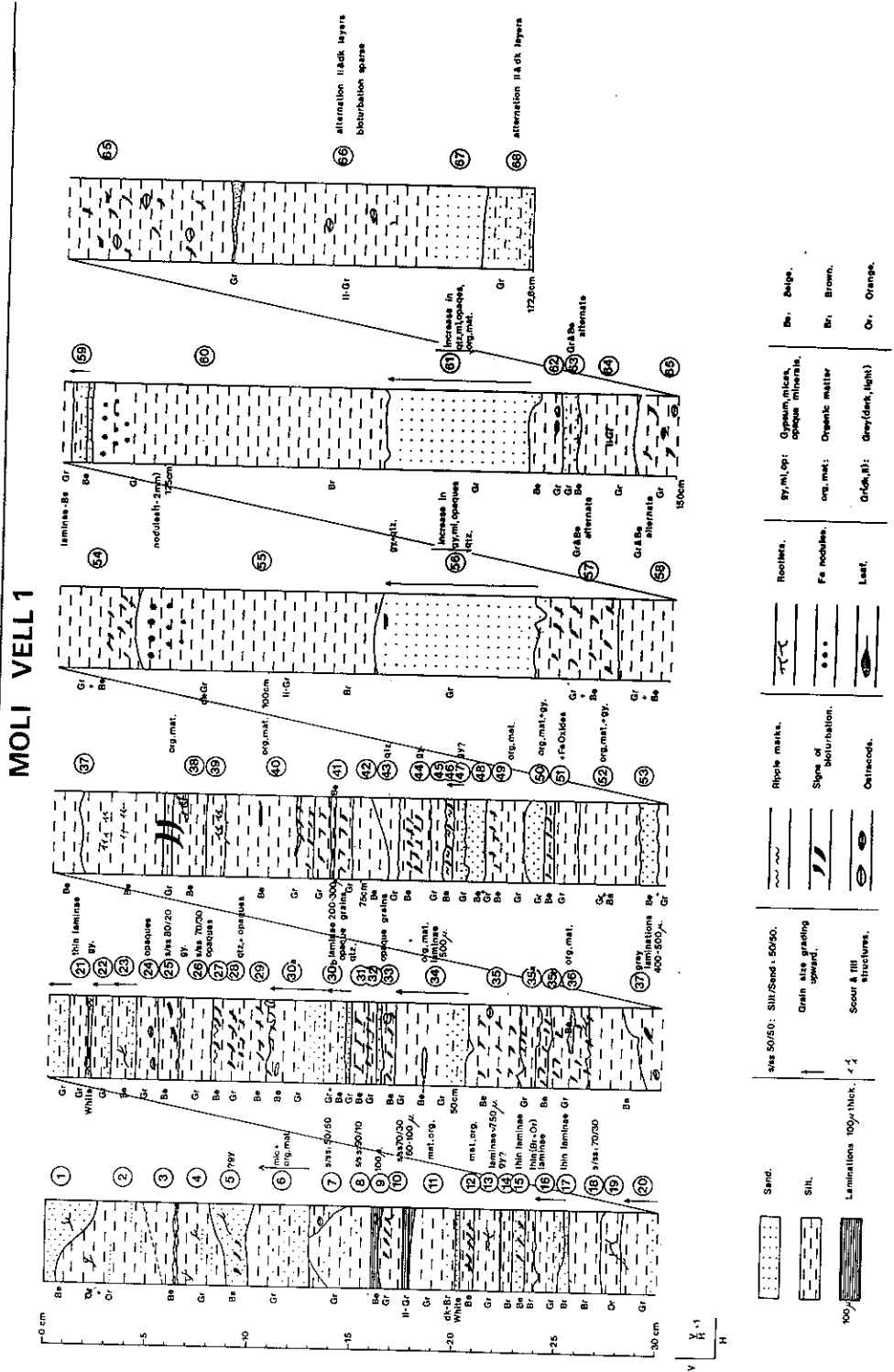


Fig. 2. Stratigraphic log of the Moli Vell I deposit showing the numbered layers from which most of the analyses (chemical, pollen, ostracod) were made. These numbers are to be preceded by the initials MV.

General description: the deposit is characterized by alternating beige and grey layers. Occasionally sandy layers occur. Bioturbation is also a common feature of this deposit.

Detailed description

(1) Beds of alternating colours. Reineck and Singh (1975) use the term "rhythmites" to describe such deposits of layers with alternating colours. The change in colour between two layers is, in most cases, very sharp (Plate I, A). The thickness of the layers varies, but the mean is about 1 cm. Some layers become thinner, or sometimes even disappear laterally, consequently allowing two layers of the same colour to become superimposed. Sometimes a thin, parallel lamination within the beige layers (becoming white in some places) can be clearly seen. There seem to be no differences in granulometry between beige and grey layers (see Fig.3). Occasionally, the bedding is wavy (Plate I, A, B); this feature does not extend into more than one layer at a time.

(2) Graded bedding in the sandy layers. Graded bedding of two different sizes is observed in the profile:

(a) Small, averaging 1 cm in thickness, and containing sandy parts with little silt (on the outcrop studied). This sand contains quartz, fragments of black shale and quartzite (= opaques in Fig.2), vegetal debris and sometimes gypsum. The contact with the underlying layer often shows signs of erosion. Occasionally, these levels occur in lenses and show ripple-mark structures.

(b) Large, averaging 20–30 cm in thickness, and consisting of the same lithologies as the smaller ones. The upper part of these levels (10–15 cm in thickness) is made up of grey clay which is dotted with black spherules (Plate I, E) up to 1 mm in diameter or occasionally more) towards the top. Within the sand part, ripple-mark structures are visible as well as small-scale channel- and fill-structures which can be seen due to the presence of dark grains (Plate I, C, D). The contact with the underlying layer also shows erosional features (Plate I, C).

(3) Scour- and fill-structures. These structures are visible at a small scale, usually less than 0.5 mm and occur at the contact between the two layers.

(4) Bioturbation. Signs of bioturbation are obvious throughout the profile. Most often, bioturbation occurs (Fig.2 and Plate I, B) from the bottom of most beige layers down into the top of most of the underlying grey layers. These areas were not sampled to avoid contamination of pollen and ostracods from one distinct layer into another. Two types of bioturbation were noticed. Both mainly consisted of thin burrows, but of varying sizes and in different orientations: (a) Vertically oriented, but occasionally horizontal, with varying lengths and an average diameter of 250 μm ; these were never branched. (b) Inclined at 45° with the base of the tube horizontal; these were occasionally branched. Average length was 400 μm and width 50 μm . The vertical burrows are probably caused by oligochaete worms and the inclined ones by chironomid larvae (Diptera). A number of rootlets

have also recently perforated some layers and helped in the destruction of some sedimentary structures. The transfer of material from upper layers into others below them is minimal, but detectable.

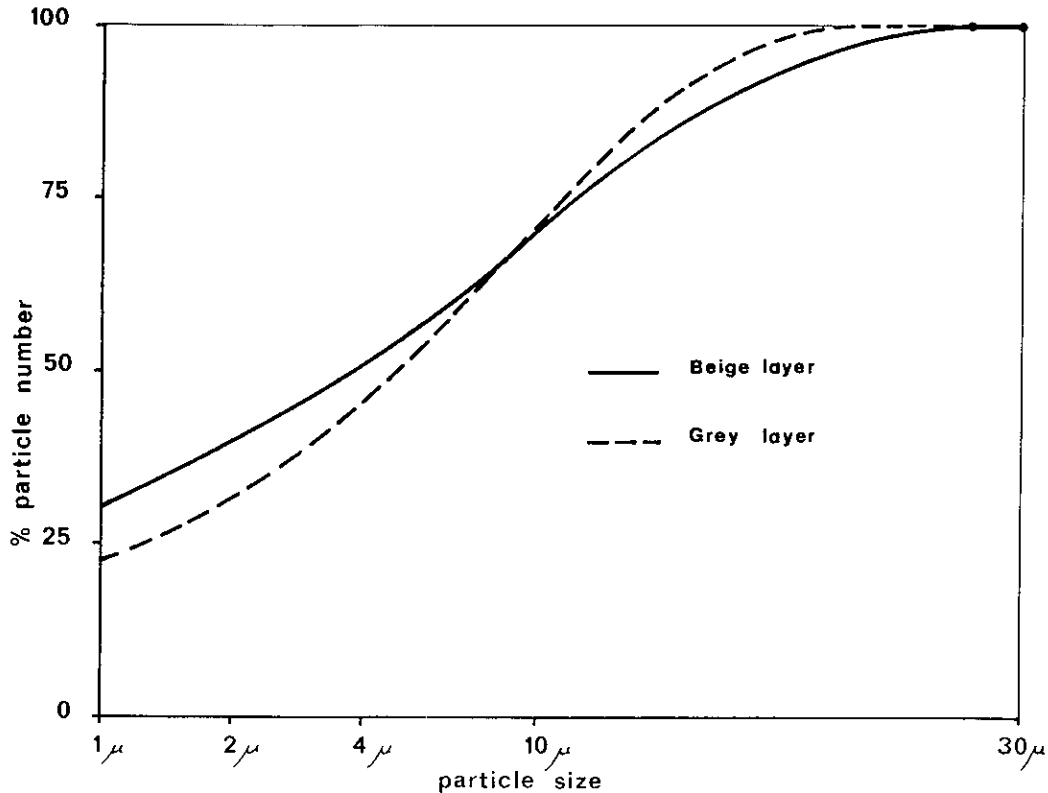
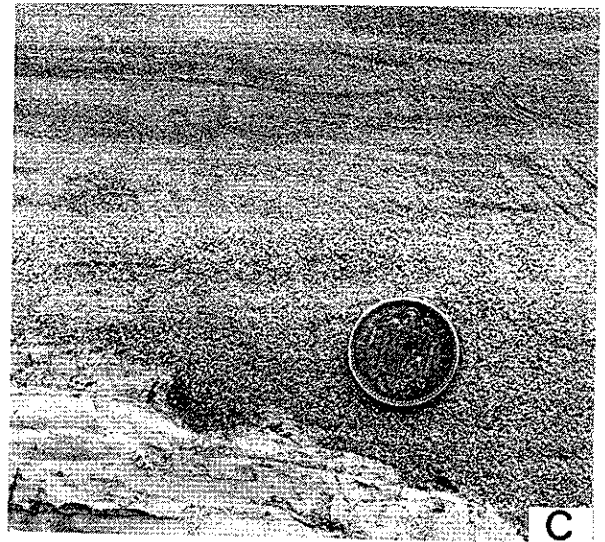
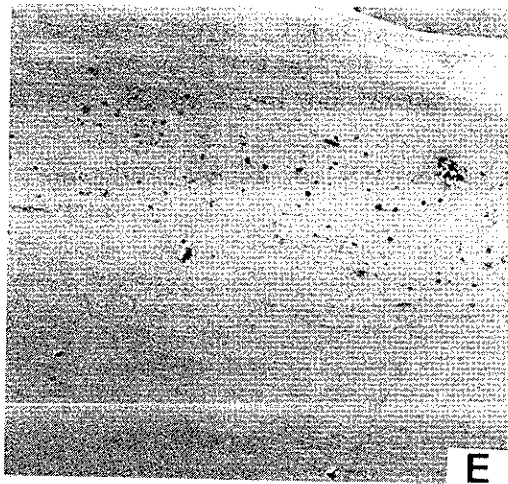
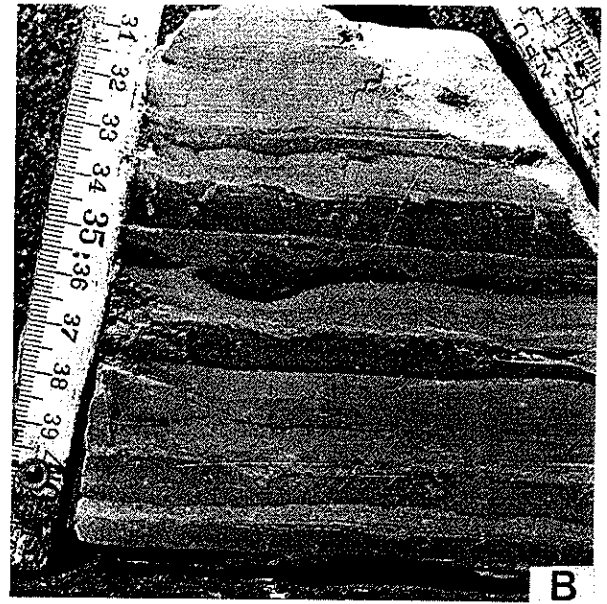
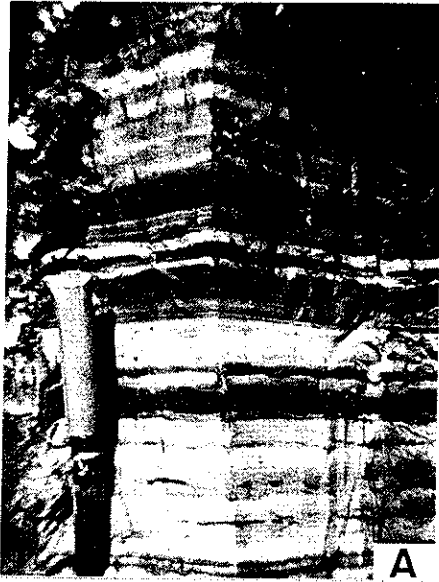


Fig.3. Graph showing (from six different grey and six other beige layers) the similarity of the average granulometry curve for twelve samples. The measurements were made with the help of a Microvideomat apparatus.

PLATE I

- A. View of a small section of the Moli Vell deposit to show the alternation of dark and light coloured silty layers. Note the irregularity in thickness of the layers.
- B. Polished slab from the Moli Vell locality to show the wavy bedding as well as the signs of bioturbation from the beige layers into the grey ones.
- C. Detailed photograph to show a graded-bedding sequence found at Moli Vell. Note the erosive contact below the coarse sand.
- D. Detailed photograph to show cross-lamination structures occurring within some of the graded-bedding sequences found at Moli Vell.
- E. Black spherules (1 mm in diameter) occurring sparsely in thick grey layer occurring at the top of a graded-bedding sequence at Moli Vell.
- F. SEM photograph of a black spherule (similar to those visible in Plate I, E) to show its framboidal aspect.



Chemical composition

In the profile studied, the mineralogical content of the sediments is characterized by the abundance of calcite and quartz accompanied by some mica and feldspars. A few thin layers consisting mainly of gypsum are also found. When analysed with X-ray diffraction methods, some levels occasionally show other peaks, which are poorly represented and are thought to belong to small spheres, about 0.5–1.0 mm in diameter. These are sometimes present in grey layers (Plate I, E) and they have a complex mineralogical composition. The majority consist of rhombohedral sulphur which, when analysed under a SEM microscope, shows the presence of bacteria which are probably responsible for their formation (Plate I, F). Also some iron sulphides, associated with greigite were found. Moreover, the external surface of these spheres is framboidal as often described for spheres found in pyrite-rich mud. The presence of these framboidal spheres with thermodynamically metastable minerals, as described by Volkov (1961) for the formation of pyrite in the Black Sea, and in correspondence to laboratory experiments developed by Berner (1970), shows that pyrite forms at low temperatures and neutral pH. This results from the reaction of sulphur with iron monosulphides.

In general, the beige layers yield more calcite than the grey layers. Analyses also show clear differences between the two types of layers: the grey ones are richer in Fe, Al, Si and S, whereas the beige ones are richer in Ca and Sr, the latter element being absent in the grey layers.

Analyses of organic carbon content on six levels (MV 25, 40, 42 which are beige layers, and MV 26, 39, 43 which are grey layers) showed that the percentage of organic carbon in the beige layers ranges between 8.0 and 9.4% and therefore is higher than that of the grey ones where percentages range between 5.0 and 5.2%.

Environmental interpretation

The Moli Vell deposit consisting mainly of rhythmites, was formed under the cyclical and chemical influences within an environment that was sheltered most of the time. A similar phenomenon is seen in the Recent meromictic Lake Banyoles with its sulphate waters ($\text{SO}_4 > \text{alc.} > \text{Cl}$). Its surface area is 12 km² and it is situated 6 km (in a direct line) from Moli Vell. At Lake Banyoles, alternating beige-yellow and dark-grey layers of rhythmites are formed in the upper parts of the lake, within some protected areas and at a depth of 10–15 m. Chemical analyses show that in the beige-yellow layers Ca, CO₃ and Sr dominate, and Fe, Si and S are impoverished in comparison to levels found in the grey layers. Consequently, a chemical similarity is shown between the Moli Vell sediments and those of Lake Banyoles mentioned above.

At Moli Vell, episodic currents affected the particular layer being formed at the time. Occasionally, a sudden supply of detritic material, either significant or minimal, and probably coming from the nearby Fluvia River, covers some parts of the bottom of the lake. The deposition of these sediments is often preceded by erosion caused by strong currents, in turn followed by turbidite

sequences. This suggests that this type of sedimentation occurred when the River Fluvia flooded into the lake. This phenomenon was previously well illustrated for Lake Brienz by Sturm (1975) and Sturm and Matter (1977) for which three main depositional environments were distinguished: delta areas, central basin plain and lateral basin slopes. In the first area, coarse sediments and rapid changes of depositional-erosional conditions occur. In the second case, low-energy conditions with deposition of fine-grained laminated muds are occasionally interrupted by high-energy turbidity currents. The last area shows low sedimentation rates.

It appears that the Moli Vell deposit could be similar to that of the central basin plain of Lake Brienz. Deposition of the alternating beige and grey layers resulted from *undercurrents* (Sturm, 1975) which transported and distributed clay and silt sediments within the entire lake basin. Sturm and Matter (1977) state that the formation of these layers was caused by *interflows* and *overflows* of normal river stages and they were deposited below the thermocline. These undercurrents flow beneath the surface water as a turbid suspension cloud at 10–25 m depth. The turbidity-current sequences are generated during high river stages and high rates of sediment supply (Sturm and Matter, 1977).

At Moli Vell, biological activity seems to have been intense during the formation of beige layers, affecting also the upper part of the underlying grey layers. This is shown by bioturbations which could have been caused, at least partly, by small worms of the type *Olygochaeta* for the vertical tubes and *Chironomidae* for those inclined at a 45° angle. The presence of gypsum-rich sand within the coarse fraction of the turbiditic sequences in the Moli Vell deposit is easily understood because Cainozoic gypsum formations are common in the Girona area and some of these could have easily been eroded away, reworked by fluvial action and finally deposited at Moli Vell.

Ostracods

Description. The samples were treated in a solution of sodium metaphosphate for a period of 24–48 h prior to being carefully washed through a 210- μm mesh sieve. The remnant sediment (coarser than 210 μm) was then dried and, from this, ostracods were picked. The samples studied bear the following numbers: MV: 11–14, 38, 39, 40 lower and upper, 41 lower and upper, 42, 43, 59, 60 i–iv and 61 i–iii (all mentioned on Fig. 2) plus AM: 1–6 belonging to another small profile at Moli Vell.

Ostracods, in abundant numbers, are found in most of the beige layers and are very rare or absent in all the grey layers. From all the MV samples, only one ostracod species, *Candona angulata* Müller is found. Length/width ratios for all valves were measured in each sample. Figs. 4 and 5 illustrate ostracods from samples MV 40, lower and MV 40, upper. The presence of molt stages (adult to A-6) of *Candona angulata* in those small samples (10 g each) leads to the conclusion that this ostracod lived in a body of still water (no transport of valves occurred) and probably in the same area through-

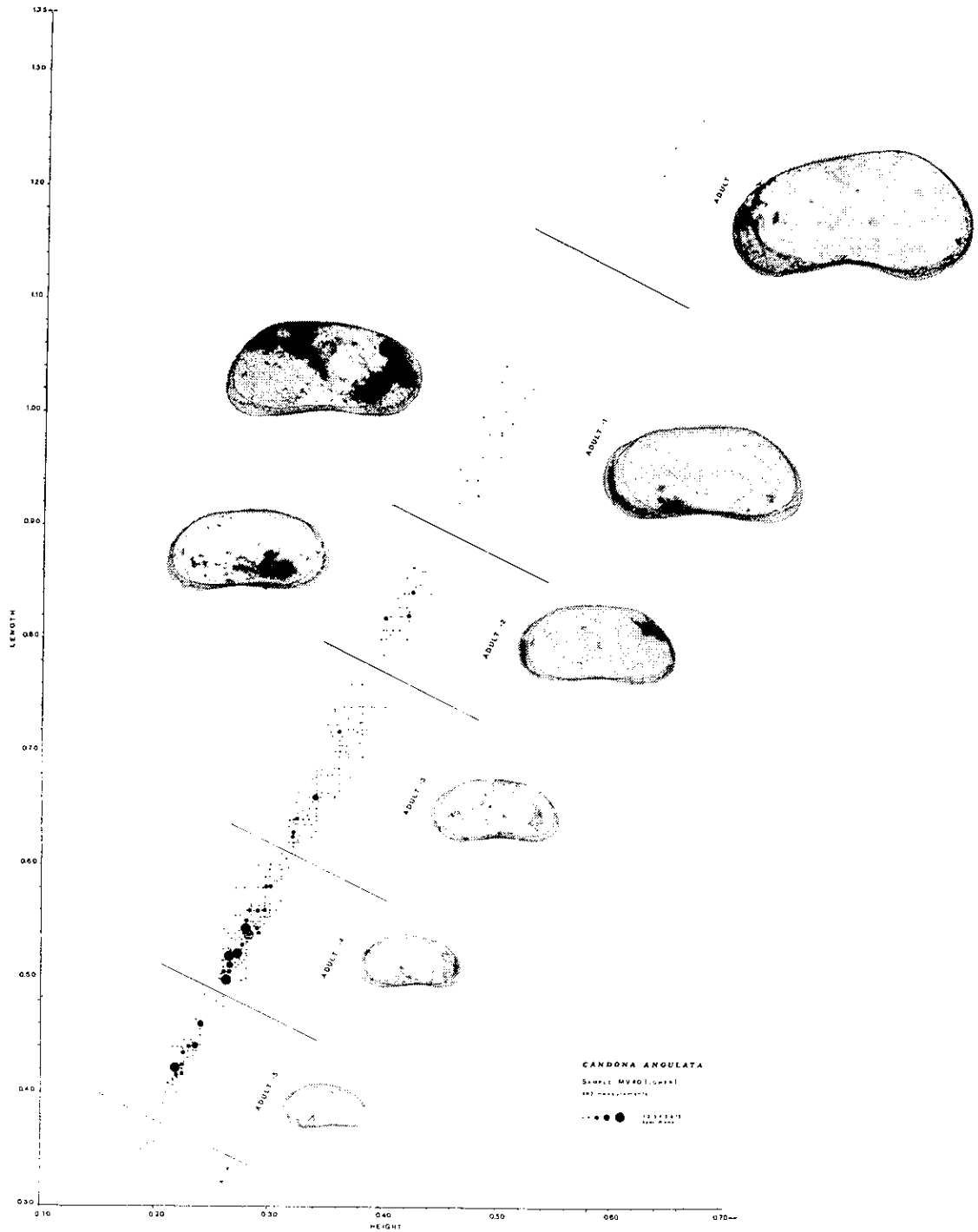


Fig. 4. Length/width measurements made on valves of the ostracod *Candona angulata* from sample MV 40, lower, showing the various molt stages. The transmitted photographs are made on ostracods typical of each molt stage and are all at the same magnification. The large blackened areas on the ostracods are caused by particles of sediment which could not be removed. The two photographs on the left are left-hand valves whereas the row of six shows right-hand valves.

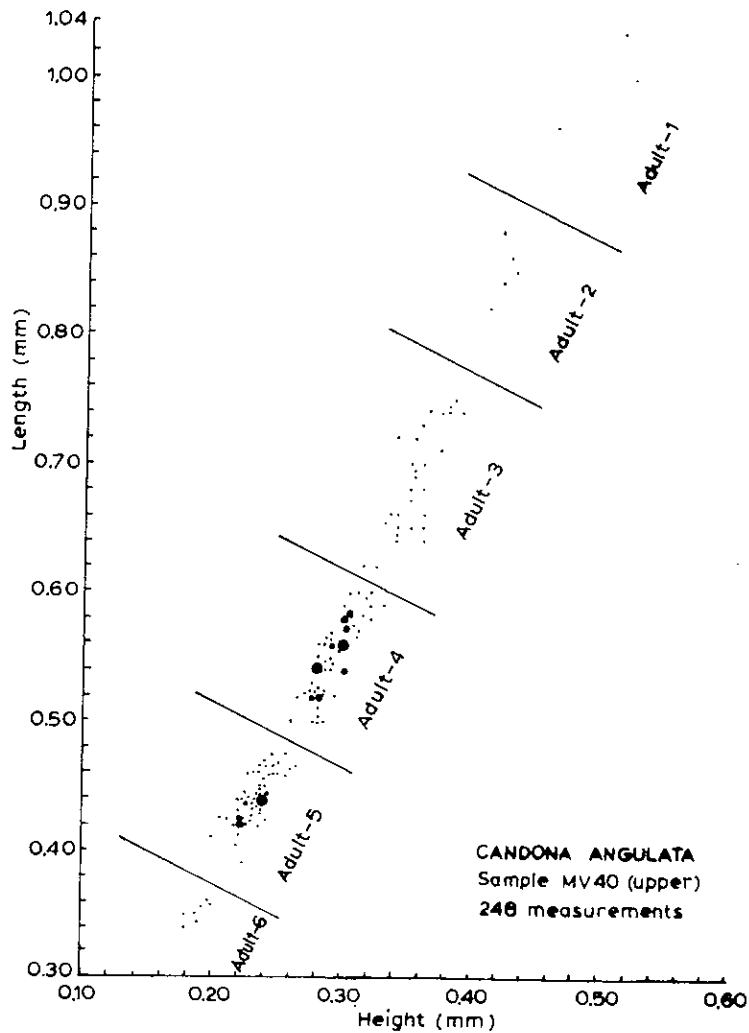


Fig. 5. Length/width measurements made on valves of the ostracod *Candona angulata* from sample MV 40, upper. Note that no adult forms were recovered.

out its life. Therefore these two samples represent a "life assemblage" of *Candona angulata*. The smaller juvenile stages, not found in the samples, were probably eliminated during the washing of the samples through the 210- μ m mesh sieve.

Candona angulata is characterized in the adult stage by a broad inner lamella which is broadest anteriorly. In adults, the carapace is highest at about 2/3 from the anterior. When viewed laterally, the posterior end forms half a circle in adult females and forms a broad angle in adult males.

In both sexes, the external surface in the posterior part of both valves is faintly reticulated. This is visible in the adult and A-1 stages.

The left valve slightly overlaps the right one, both anteriorly and posteriorly. The radial pore canals are numerous and all straight. They are also visible in the strongly incurved mouth area of the valves in adult females.

In all juvenile stages, sexual dimorphism is not detectable. The dorsal area, when seen in lateral view, is firstly almost straight in stage A-2, but then becomes more inclined towards the posterior as the ostracod is younger (Fig. 4).

In the MV samples, the following ostracods were found:

- MV 11: juvenile ostracod, similar to those of sample MV 40
 MV 12: none
 MV 13: ostracods of valves belonging to all stages of *C. angulata*
 MV 14: none
 MV 38: many valves belonging to all stages of *C. angulata*
 MV 39: none
 MV 40, lower } many valves belonging to all stages of *C. angulata*
 40, upper }
 MV 41, lower } none
 41, upper }
 MV 42: many valves belonging to all stages of *C. angulata*
 MV 59: two juvenile valves + four fragments of *C. angulata*
 MV 60: i—iv: no ostracods
 MV 61 i: none
 ii: two fragments of a juvenile of *C. angulata*
 iii: one juvenile *C. angulata*.

The AM samples present the same phenomena as the MV ones: ostracods are abundant in the beige layers and are rare or absent in the grey ones. *C. angulata* is again abundant, with valves belonging to stages from A-5 to adult. However, in sample AM 1, a few juvenile specimens of *Ilyocypris bradyi* Sars 1890, are present, accompanied by one juvenile of *Herpetocypris* sp. and *Paralimnocythere* sp. In beige sample AM6, no ostracods were present but this could be explained by the presence of many gypsum crystals, indicating perhaps that the environment of deposition of this layer was one of high-salinity conditions.

Small fecal pellets are abundant in beige layers where ostracods are present. These are thought to belong to the ostracods as their cylindrical shape and size correspond to those found today in aquaria where similar ostracods are kept.

Palaeoecology. *C. angulata* is a typical spring-form ostracod, whose eggs hatch during spring and most individuals reach maturity during that season. Klie (1939) showed that it is an ostracod commonly found in slightly alkaline waters. As the beige layers yielded at least all the last juvenile stages as well as a few adult forms of *C. angulata*, it can be suggested that these layers were deposited during springtime. The lack of ostracods in the grey layers, on the other hand, suggests that their deposition took place towards the end of spring or after it, and until the next spring. Benson (1969) described a similar phenomenon for the Rita Blanca Lake deposits, where abundant blooming of ostracods (*Limnocythere* sp. and *Cyprideis* sp.) in light-coloured, calcareous-rich layers occurred just after the spring flood water with late bloomers

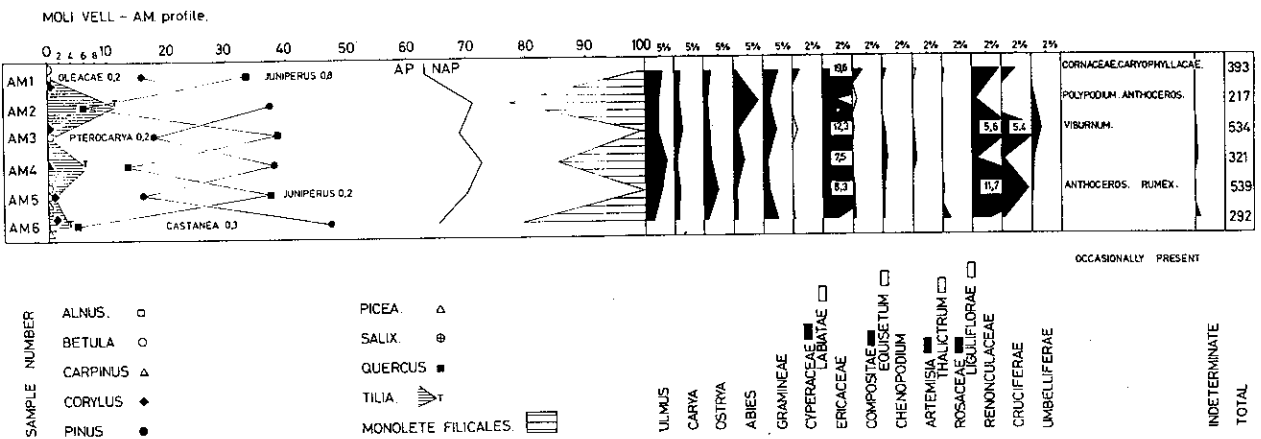
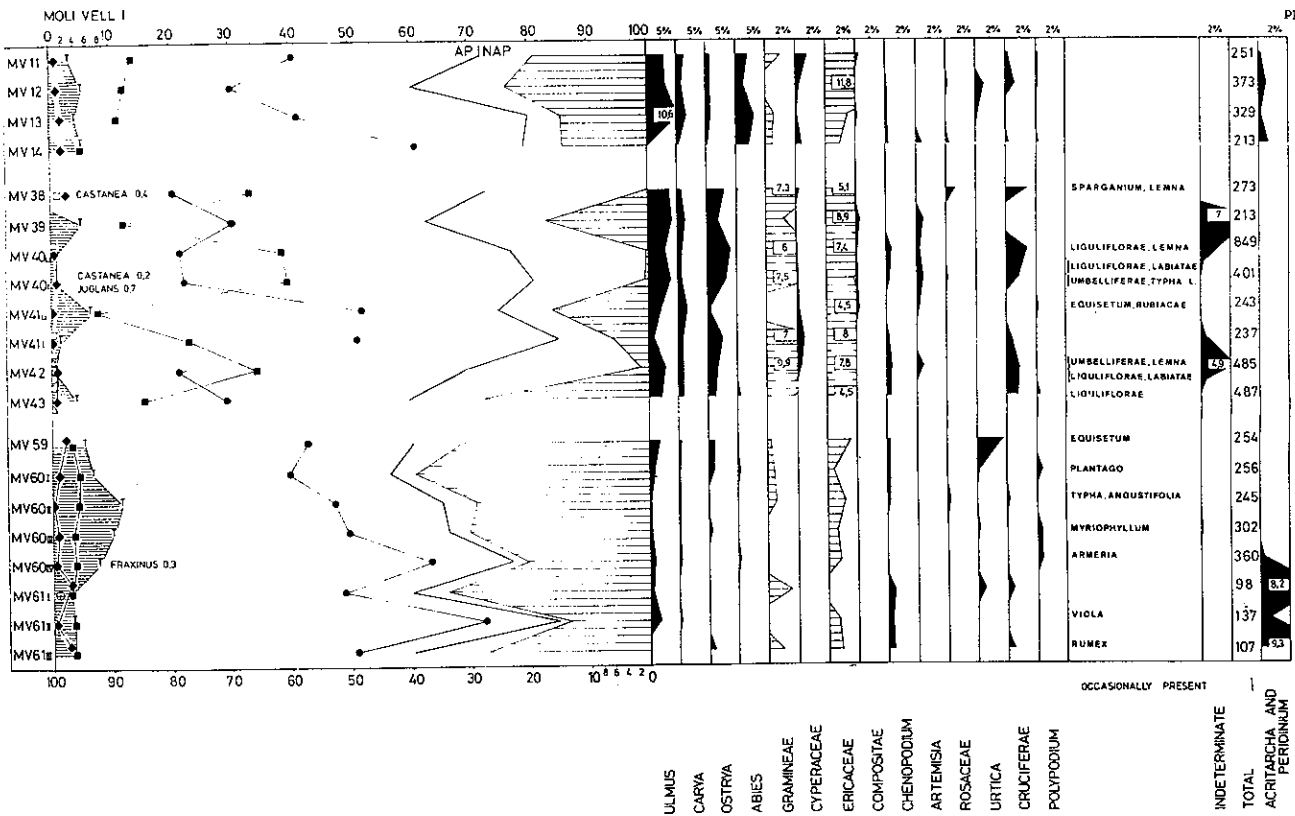


Fig. 6. Pollen diagrams of the Moli Vell I and AM profiles.

(*Candona* sp., some *Limnocythere* sp.) appearing in the dark layers deposited later.

At Moli Vell, deposition of at least the beige layers must have occurred under slightly saline conditions — Neale (1964), for example, gave a salinity range for *C. angulata* of 0.4–13‰ — and this type of environment is confirmed by sample AM 1 where *Ilyocypris bradyi* is found. This species is still recorded in Lake Banyoles and is also found today in temporary ponds in the same area together with *Heterocypris salina* (Brady, 1868). Another confirmation of this is the postulated presence of waters of varying salinities during the deposition of the Moli Vell sequence shown by occasional layers consisting almost entirely of gypsum (Fig.2).

The presence of ostracod fecal pellets in beige layers tends to confirm the idea that biological activity was less important or perhaps minimal during the deposition of grey layers which show no signs of bioturbation. It is thought that ostracods, chironomid larvae and oligochaete worms were not present during the formation of grey layers.

Stratigraphy. No stratigraphical information can be extracted from the presence of the ostracods found in the MV and AM samples as these ostracods were common throughout the entire Pleistocene and are also found living today in areas of Europe and North Africa.

Palynology

The palynological content of twenty samples was examined and the description is shown in the Moli Vell I diagram (Fig.6). These samples were treated following Frenzel's (1964) method, simplified later by Bastin (1971). The percentages were computed in relation to the total of arboreal and herbaceous species. The presence of acritarchs was noted and they were counted separately from the total.

Description of the Moli Vell I diagram. This diagram is divided into three vegetational phases each corresponding to a series of levels. These three phases represent a landscape covered with trees, with an AP/T ratio superior to 50% and with a mean of 70.6%.

(1) The first phase, from sample 61iii to sample 59, is largely dominated by *Pinus* followed by *Tilia* which reaches 11.8% at level 60ii. The percentages of *Quercus* range between 3.1 and 4.7%. *Ulmus* is present from level 61ii to level 59. *Corylus* is also almost continuously present. The presence of the thermophilous exotic *Carya* is noted as well as sporadically *Ostrya*, *Abies*, *Fraxinus* and *Salix*.

The herbaceous species are dominated by monolete spores of pteridophytes among which *Dryopteris* is recognized. Subcontinuous curves of Ericales, Gramineae, *Chenopodium* and *Urtica* are observed and to a lesser extent Cruciferae, Rosaceae, *Polypodium* and trilete spores of pteridophytes. The sporadic taxa are not represented in the diagram: these are *Typha latifolia*,

Typha angustifolia, *Myriophyllum*, *Rumex*, *Viola*, *Armeria* and *Equisetum*. Finally, the abundance of acritarchs, at the base of the diagram, seems to indicate the supply of ancient materials.

(2) The second phase, from samples 43 to 38, is characterized by the concurrence of *Pinus* and *Quercus* and by a great variation of their percentages. *Ulmus* extends slightly and exceeds 5% more than once. *Tilia* is less abundant; it extends when *Pinus* dominates and regresses when *Quercus* dominates. *Ostrya* and *Carya* form continuous curves, and *Corylus*, which is less abundant, shows a subcontinuous curve. Some species are sporadically represented; these are: *Alnus*, *Betula*, *Carpinus*, *Castanea*, *Juglans*, *Picea* and *Abies*. Among the herbaceous species an obvious regression of the monolet spores appears during the periods of extension of *Quercus*. Ericales form a continuous curve and reach 8.9% at sample 39. Gramineae also extend but do not form a continuous curve. This is similar for Cruciferae, but to a smaller extent. Rosales and Chenopodiaceae are maintained in subcontinuous curves. More species appear sporadically: *Sparganium*, *Lemna*, *Typha latifolia*, Ranunculaceae, Labiatae, Umbelliferae, Rubiaceae, Liguliflorae, *Equisetum*, *Polypodium* and few trilete spores and indeterminate tricolpate pollen grains. Acritarchs are absent.

(3) In the third phase, from samples 14 to 11: vegetation is dominated by *Pinus* while *Quercus* extends from 5.2 to 13.9%. *Tilia* does not extend further than 5.4%. *Ulmus* reaches a maximum of 10.6% in sample 13. *Corylus* and *Carya* maintain a continuous curve. *Ostrya* decreases while *Abies* extends in a continuous curve and reaches 6.1% in sample 13.

The herbaceous species are dominated by monolet pteridophytes (among them is *Dryopteris*) followed by Ericales, Cyperaceae, Gramineae, Cruciferae and *Polypodium*. Few pollen grains of Compositae, *Urtica*, Rosaceae, *Artemisia* and a trilete pteridophyte spore are found. The presence of acritarchs is again noticed.

Palaeoclimatological and palaeoecological interpretation

Palaeoclimate. The first phase is characterized by a *Pinus* forest. The mean percentage of *Pinus* reaches 52%. *Quercus* is poorly developed (mean 3.8%) as well as the mixed oak-forest (*Quercus*—*Tilia*—*Ulmus*) (mean 12.2%). *Carya* (exotic thermophilous) is poorly represented. The landscape suggests climatic conditions cooler than those which occur in this region today where oak forests appear to be more developed. In fact, analyses of the sediments of the Lake Banyoles plain demonstrated Holocene spectra in which *Quercus* dominates over *Pinus* (unpublished results). On the other hand, Menendez Amor (1966) described palynological results near Lake Banyoles related to the Boreal period in which *Pinus* never reached a percentage higher than 50 and *Quercus* never exceeded 25%. She considers this period as more continental and colder than today. From this data, it is probable that the first phase at Moli Vell, was cooler than the subactual and actual ones within the region studied.

The second phase seems to indicate a climatic improvement. In fact, the thermophilous species extend to the detriment of *Pinus*, which has a mean percentage of 31.1, and its maximum is inferior to the mean percentage of the previous phase. The mixed-oak forest reached a mean of 33.7% and the minimum percentage of *Quercus* remains superior to the maximum reached within the preceding phase. The development of *Carya* and *Ostrya*, which were weakly represented previously, is also noted.

The third phase is perhaps slightly cooler than the preceding one, but appears on the other hand to be warmer than the first. The mean percentage of *Quercetum mixtum* is 20.9, but *Carya* is maintained and is sometimes even higher. However, this phase is characterized by the appearance of a continuous *Abies* curve, and it appears to be more humid than the previous ones.

Overall, we can suggest the existence of a temperate climate, cooler than today, in the first phase, and, without any doubt, warmer than today in the second and third phases.

Environmental reconstruction. This diagram presents large variations for *Pinus*, *Quercus*, *Tilia* and monolete spores percentages within the second phase. These large variations in such a small thickness of sediment (11 cm) are hardly to be interpreted from the point of view of stratigraphical and palaeoclimatic evolution.

On the other hand, we notice that the dominance of *Quercus* only appears within beige sediments, whereas the dominances of *Pinus*, accompanied by the *Tilia* extension and monolete spores, appear in the layers of grey sediments. This phenomenon was also observed in samples taken in three beige and three grey layers collected previously at the same site and which we cannot locate accurately on the diagram Moli Vell I.

A simplified diagram (AM) of these samples is presented in Fig.6. Finally, the analysis of the fauna reveals abundant numbers of ostracods within beige layers and very few to none within the grey layers. From these data, two hypotheses are offered:

The first is that of a rapid sedimentation which registers seasonal variations of the pollen rain (phenomenon described in *Phormidium incrustatum* travertines in Belgium — Geurts, 1976). This hypothesis is based on the comparison of the diagram with the Recent palynological calendars of Spain (Suriniach, 1974). However, it is necessary to show the importance of the fact that the old phenological successions were not necessarily identical to those of Recent rhythms. In Catalonia, *Tilia* pollinates in summer from the end of May until the beginning of September. *Quercus* pollinates in April and May. Pinaceae pollinate from mid-February to August with a peak at the end of March — beginning of April, and another one at the end of May — beginning of June. With this information one can suspect a seasonal sedimentation. The high percentages of *Quercus* within the beige layers suggest their deposition during spring (perhaps April—May). On the other hand, the high

percentages of *Pinus*, and especially *Tilia*, suggest that sedimentation started at the end of May — beginning of June and continued during summer.

The second hypothesis is that of a differential destruction of *Pinus* and *Tilia* pollen through their digestion by ostracods which are abundant in the grey layers. To test this hypothesis, the following experiment was carried out.

Fresh pollen of *Pinus*, *Alnus*, *Corylus* and *Fraxinus* was examined with the aid of a binocular microscope and was then fed to ostracods. After the ingestion of the pollen grains, the faeces were collected and analysed for their pollen content.

The results show that air disappeared from the air sacs of the *Pinus* pollen and that the exine of the distal pole was altered. The internal membrane and the cytoplasm of many pollen grains were partially destroyed, probably during the ingestion. The same phenomenon was observed for pollen which passed through the digestive tract of bees (Stanley and Linskens, 1974, p. 100 ff.).

Few pollen grains were torn as the mechanical action was very limited. One can conclude that the presence of ostracods does not seem to affect the palynological spectra of sediments, since, in spite of the passage of pollen through the digestive tract of ostracods, the exine, an important feature in taxonomy, is still identifiable. The second hypothesis is, therefore, eliminated at present and the first one is preferred.

The palynological analysis rather suggests a seasonal sedimentation of grey layers in summer and of beige ones during spring. It is precisely in the beige layers that *Candona angulata*, a typical spring-form ostracod, is abundant. The palynological data suggest that there is no supply of ancient material or reworking because these layers are devoid of acritarchs.

Stratigraphy. Because of the scarcity of palynological data in Catalonia, this piece of preliminary work only provides us with a working hypothesis. The diagram suggests a climatic warming up. It is characterized by the presence of *Carya*, an exotic thermophilous tree. *Castanea* and *Juglans* sporadically present in the Moli Vell I deposit are also exotic thermophilous species (Elhaï, 1969).

At Padul, in the south of Spain, the Granada Interstadial period, considered as probably equivalent to the Holsteinian Stage and its preceding cool period, do not have or no longer have *Carya* (Florschütz et al., 1970). If *Carya* no longer existed during this period in the south of Spain, there is little chance that it was maintained during the same period in Catalonia. This leads to the suggestion that the Moli Vell sediments are older than the Granada Interstadial.

On the other hand, in the Senezian I of the French Massif Central (suggested as being contemporaneous with the Waalian Stage by Elhaï, 1969), *Carya* is present among a group of still well diversified and relatively abundant exotic thermophilous species. It is, therefore, thought that the Moli Vell sedi-

ments, situated further south, and which only contain *Carya* with very sporadic *Castanea* and *Juglans* as exotic thermophilous indicators, are more recent than the Senezian I period. Consequently, the diagram studied here suggests that the Moli Vell deposit was formed between the Senezian I (= Waalian) and Granada Interstadial (= Holsteinian) periods.

GENERAL INTERPRETATION

In the studied profile, an alternation of grey and beige silty layers, (= rhythmites), usually each 1 cm thick, is evident. This difference is also marked in the chemical composition of these two layers, the beige layers being richer in organic carbon, CO₃, Ca and Sr, and less rich in Fe, Al, Si and S than the grey layers. Bioturbation is common within the beige layers and this often affects the upper part of the underlying grey layer. On the other hand, the contact of a beige layer with a grey one is generally sharp and the base of the grey layer is nearly always dark. In spite of the beige layers being bioturbated, a thin lamination is sometimes visible. Sandy layers, with graded-bedding structures, occasionally interrupt the alternation of grey and beige layers; at the base of almost all of these graded beds, the sediment content increases in quartz, mica, black shale and quartzite fragments.

In the beige layers, the ostracod *Candona angulata* abounds. Few adult and many juvenile valves of this ostracod are found. It is also, in rare cases, accompanied by *Ilyocypris bradyi*, *Herpetocypris* sp. and *Paralimnocythere* sp. In this layer, fecal pellets, probably of ostracods, are common. In the grey layers, on the other hand, ostracod valves and fecal pellets are absent or very rare.

Quercus pollen abounds in the beige layers whereas that of *Tilia* and *Pinus* dominates in the grey ones.

Reworked acritarchs are also found in layers with graded-bedding structures. *Tilia* too is characteristic of this deposit.

In light of the data presented above, the following environmental interpretation of the Moli Vell deposit is presented:

(1) Sediments were deposited within a shallow lake, consisting of alkaline and sulphate water. Occasional floods of a nearby river supplied the lake with detritic sediments and acritarchs.

(2) The dynamics of the lake were characterized by two important stages indicated by the pollen and ostracod analyses:

(A) The first is characterized by deposition of beige layers corresponding to a period of stable thermal stratification during which biological activity was intense. Spring-time vegetation was shown here by the abundance of *Quercus* pollen. The ostracod *Candona angulata*, a spring form, is prolific at this level in which a vast quantity of fecal pellets was also found. As this ostracod is usually found in waters of low salinity (0.4–13‰), its presence indicates that the water was probably slightly alkaline (also suggested by the presence of *Ilyocypris bradyi*). Bioturbation was also important during deposition of that layer. It was probably mainly caused by chironomid larvae

and oligochaete worms.

(B) The second layer is distinguished by the deposition of grey layers. This change is sharp and occurs at the beginning of summer during the time of pollination of *Pinus*, and especially *Tilia*, the latter only being typical of the beginning of this season. Traces of biological activity, within this type of layer, or signs of bioturbations plus ostracod valves and pellets are absent or very rare. At a particular moment, vertical mixing of waters occurred accompanied by oxidation of Fe.

These rhythmites are, therefore, seasonal. Occasionally, floods from a nearby river, probably the Fluvia, interrupted the rhythmical sedimentation of grey and beige layers and caused the deposition of turbidite sediments.

The location of this deposit was very likely in the central plain of a lake basin, similar to the one described by Sturm (1975) for Lake Brienz, where fine-grained laminated muds are occasionally covered with turbidite sequences.

During the formation of the Moli Vell deposit, the climate was evolving towards a general warming up. The presence of *Carya*, accompanied only by a few pollen grains of *Juglans* and *Castanea*, suggests an intermediate age between Senezian I and Granada Interstadial periods for the formation of the deposit.

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