Organic matter and palynology of DSDP site 367 Pliocene-Pleistocene cores off West Africa

Pollen
Organic matter
Pleistocene
Ocean
Africa

Pollen
Matière organique
Pleistocène
Océan
Afrique

R. Bonnefille [a], M. Rossignol-Strick [b], G. Riollet [a]

[a] Laboratoire de Géologie du Quaternaire, CNRS, Faculté des Sciences de Luminy, Case 907, 13288 Marseille Cedex 9.
[b] Laboratoire de Palynologie, Muséum National d'Histoire Naturelle, 61 rue de Buffon, 75005 Paris.

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ABSTRACT

Patterns of deposition of organic matter from marine and continental origins in the deep marine environment on the rise of a passive continental margin (DSDP 367, Cape Verde Basin) during part of the Pliocene and Pleistocene are described by means of ponderal, volumetric and transmitted light microscopic analysis, following petroleum geology technique as well as pollen analysis.
In such a deposit, which is not primary fluviatile, the dominant pollen source area is the inland gramineae savanna, followed by the littoral vegetation suggesting a significant amount of eolian transport. This is an important fact to take into account when fossil marine pollen spectra are used to reconstruct past source environments. In the Quaternary, while the savanna is always present, although fluctuating, the variations of the tropical littoral vegetation are sharper and have been correlated with the global climatic sea-level and rainfall fluctuations.

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RÉSUMÉ

Matière organique et palynologie
de niveaux pliocènes et pléistocènes du site DSDP 367
au large de l'Afrique de l'Ouest.

Ce travail présente une étude de la matière organique d'origine marine et continentale de sondages DSDP site 367 pléistocènes et en partie pliocènes, prélevés en milieu marin abyssal dans le bassin du Cap Vert. Les descriptions utilisent les techniques de géologie pétrolière, analyses pondérale, volumétrique, microscopique en lumière transmise et analyse pollinique. Dans ce type de dépôt, qui n'est pas fluviatile primaire, l'aire origine dominante des pollens apparaît être les savanes à graminées et la végétation littorale, ce qui suggère un transport éolien non négligeable. C'est un fait important à considérer dans la reconstitution des paléoenvironnements à partir des analyses polliniques d'anciens milieux marins. Au Quaternaire, la zone de savane est toujours présente, quoique fluctuante, les variations de la végétation littorale, humide ou aride, sont plus marquées et peuvent être corrélées avec les variations climatiques globales du niveau marin et de la pluviosité.

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INTRODUCTION

The organic matter depositing on the ocean floor originates from both marine and continental sources. By applying petroleum geology techniques one can evaluate the fraction from each origin, and describe their deposition patterns through time. It is then possible to decipher the relative influence of rivers and winds, the degree of reducing conditions on the sea floor. Vegetation history and also climatic history are more directly documented by pollen analysis which is used both as a control and as an independent tool.

The Upper Quaternary vegetational and climatic history of tropical Western Africa is presently most continuously documented by pollen analysis of Eastern Atlantic marine cores (Agwu, 1979; Rossignol-Strick, Duzer, 1979). Pollen analysis of the upper cores of DSDP site 367, leg 41, is presented here.

CORE SITE, LITHOLOGY

Site 367, 12°29'N-20°02' W is located in the Cape Verde Basin off West Africa, on the lower Continental Rise, at 4 748 m water depth (Lancelot *et al.*, 1977), 250 km west of the shelf edge, and 370 km from the coast line. Facing the mouth of the Saloun River, it is outside the present-day influence of the Kayar Canyon system (Sarnthein, 1978; Fig. 1).

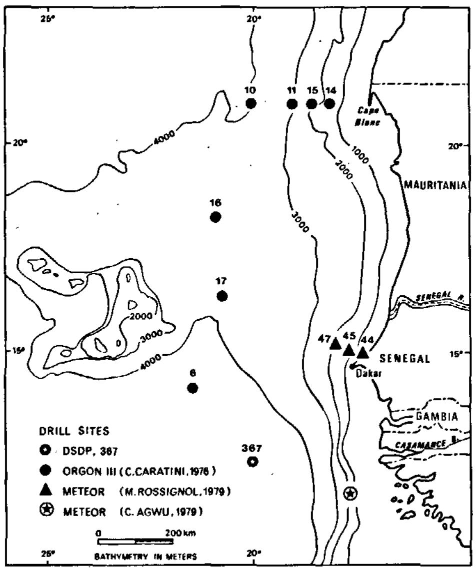

Figure 1
Cores location
Localisation des sondages.

Quaternary sediments of cores 1 and 2, and Pliocene sediments of cores 4 and 5 are composed of deep water turbidites, mostly foraminifer nannofossil marls interbedded with silty clays and sands with heterogenous assemblages of microfauna and flora. These terrigenous sediments are redeposited from shallow water environment, carried downslope to the lower Continental Rise through the numerous incisions on the adjacent continental slope of the rapidly prograding continental shelf off southern Senegal and Guinea. Accumulation rate is high (90 m/10^6 year) (Cepek *et al.*, 1977). Intense drilling disturbance in these cores (Lancelot *et al.*, 1977, Pflaumann, Krasheninnikov, 1978), incite to exercise great caution when drawing conclusions.

The few sandy layers intercalated in Pleistocene cores 1 and 2 are fluviatile turbidites from river deltas, thoses of Pliocene cores 4 and 5 are eolian dunes turbidites (Sarnthein, 1978).

There is a 36 m uncored interval between the 17.5 m thick Quaternary sediments and the Pliocene levels.

STRATIGRAPHIC RANGE AND CHRONOLOGY

Pflaumann and Krasheninnikov (1978) indicate that core 1 could be assigned to the foraminifer *Globigerina calida calida* subzone, the middle subzone of zone N23. Core 2 would belong to the *Globorotalia crassiformis hessi* subzone, within zone N22.

Correlation with the Ericson and Wollin zonation and oxygen isotope stratigraphy in the Western Equatorial Atlantic (Rogl, Bolli, 1973), indicates that the *Globorotalia calida calida* subzone which is accepted as isochronous with the Eemian (last) Interglacial, and the beginning of the last Glacial (Shackleton, 1969) corresponds to most of zone X, or oxygen isotope stage 5. The *Globorotalia hessi* subzone corresponds to zones V, W (probably the penultimate glaciation) and the beginning of zone X, or oxygen isotope stages 7 and/or older, 6, and the beginning of stage 5.

Cores 3 and 4 contain a Pliocene foraminifer microfauna with Miocene reworking. Core 3 is attributed to the *Discoaster surculus* coccolith subzone, and core 4, to the *Discoaster tamalis* subzone (Lancelot *et al.*, 1977).

However, unpublished foraminiferal data by L. Blanc-Vernet do not support such a stratigraphical precision, given the general paucity, poor preservation of individuals, and frequent transport of the benthos from the neritic zone. Cores 1 and 2 are therefore assigned more generally to post 700 000 BP Pleistocene, while core 4 is highly mixed. Nannoplankton analysis by M. Clocchiatti (unpubl. data), after pointing to unfavorable conditions, suggests for core 1 an age between 200 000 BP and 300 000 or 350 000 BP, for core 2 until 450 000 or 500 000 BP, and for core 4, around 2×10^6 to 2.5×10^6 BP.

We shall opt here for these more cautious estimates.

PREPARATION METHOD AND ABSOLUTE QUANTITATIVE MEASUREMENTS OF ORGANIC MATTER AND POLLEN

Technique and results

The sediment water percentage is measured after 12 hours desiccation at 50°C. A humid sample equivalent to 10 g of dry sediment is demineralized with 10% HCl, 70% HF, hot 10% HCl. The insoluble organic residue (kerogen) volume is measured with a micropipette

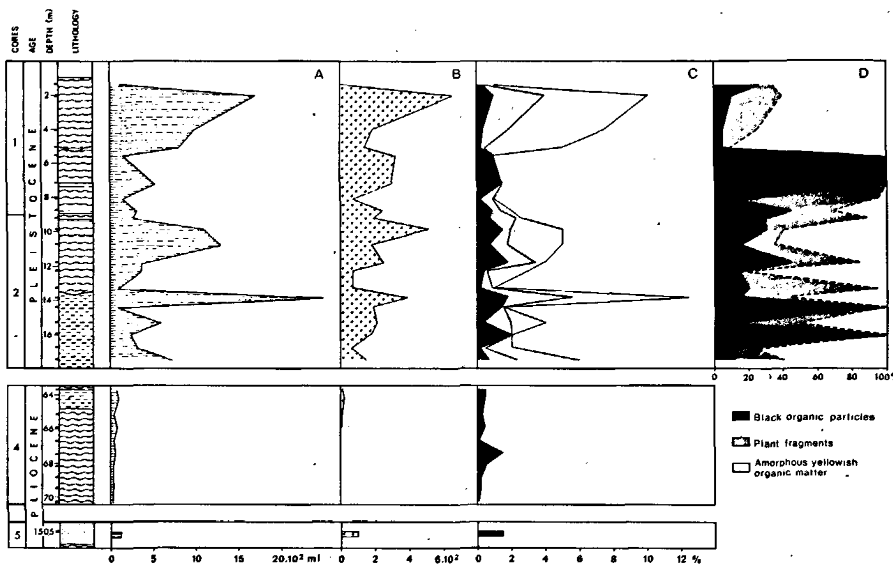

Figure 2

Organic matter residue: A, volume per gram of dry weight; B, pollen absolute frequency per gram of dry weight; C, surface percentage of the transmitted light microscopical field; D, palynofacies, percentages of total organic matter.

Étude de la matière organique: A, mesure volumétrique par gramme de poids sec; B, fréquence absolue des pollens par gramme de poids sec; C et D, palynofaciès; C : composition pourcentage d'occupation du champ optique; D : pourcentages par rapport à la matière organique totale : particules organiques carbonisées; débris végétaux; matière organique amorphe.

then diluted to 30 ml (Fig. 2 A), Kerogen surface percentages and palynofacies (Fig. 2 C, D) are evaluated on a 1/10 fraction, through comparison with the "Compagnie Française des Pétroles" (Fediawsky) percentage chart. Palynofacies is composed of black organic particles, plant fragments, amorphous yellowish organic matter (Fig. 2 D) (Combaz, 1964; Correia, 1969; Tissot *et al.*, 1978; Tissot, Welte, 1978; Habib, 1979).

Absolute pollen frequencies (Fig. 2 B) are measured on the remaining 9/10 organic residue fraction, after ebullition in 10% KOH, centrifugation, and dilution in a known volume of glycerin. From the volume v of this dilution is taken a 25 µl fraction in which n is the sum of all the pollen grains. The pollen absolute frequency per gram dry weight, N, is given by:

$$N = \frac{n \times v}{25} \times \frac{10}{9} \times \frac{1}{10}.$$

Interpretation

Most Pliocene levels are devoid of pollen. Pleistocene pollen absolute frequencies are lower than in cores closer to the coast (Rossignol-Strick, Duzer, 1979). They correlate rather well with organic residue volumes (Fig. 2 *A*, *B*), which in turn correlate well with surface percentages (Fig. 2 *A*, *C*). Amorphous yellow organic matter (AYOM) is generally the dominant element, and can be tentatively identified as chemical Type II kerogen, of phyto- and zooplanktonic origin, deposited in reducing environment (Tissot *et al.*, 1974; Tissot, Welte, 1978, p. 144), or sapropelic kerogen in optical microscope palynofacies analysis (Tissot, Welte, 1978, p. 128).

In sediment traps superposed in the water column of the Western Equatorial Atlantic, 750 km east of Guyana, the organic matter of planktonic origin is dominant through the water column, although lower abundances of terrigenous organic matter indicating long range transport, also occur (Wakeham *et al.*, 1980). The mostly marine origin of AYOM is suggested here by its poor correlation with terrigenous plant fragments (PF) (Fig. 2 *C*). Fom PF, derives chemical type III kerogen, or palynofacies humic kerogen frequent in thick sedimentary sequences along continental margins (Tissot, Welte, 1978, p. 144). Black organic particles, (BOP) (coaly debris, or residual kerogen), result probably from intense weathering, oxydation and carbonization in subaerial soils, and often reworking of terrestrial organic material (Tissot *et al.*, 1979; Tissot, Welte, 1978, p. 128). They do not correlate with the other organic elements (Fig. 2 *C*, *A*), which suggests they are not susceptible to the sea-floor redox conditions. Indeed, they dominate the palynofacies only when the organic matter residue is very low.

High pollen absolute frequencies correlate mostly whith AYOM, less well with PF, and not with BOP (Fig. 2 *B*, *C*). This means that favorable preservation conditions on the sea floor (fast burial, protecting from oxydation) would affect similarly pollen and AYOM, and also that not all pollen is transported like plant fragments, by rivers: some pollen is wind-transported. Maxima of plant fragments always coincide with highest pollen absolute frequencies (2 and 4 m) (Fig. 2 *C*, *B*), which points to a common and most efficient fluviatile transport from the continental production area. Rivers are the main pollen transport agent to the sea, but it is not exclusive. Pollen transport by wind from inland or an origin in the littoral vegetation may account for high pollen absolute frequency unmatched by plant fragments as occurs at 10 m (Fig. 2 *B*, *C*), with abundant mangrove and Gramineae (Fig. 5). It should also be mentioned that eolian transport of woody debris do occur off Western Africa, together with opal phytoliths and fresh-water diatoms (Folger, 1970; Emery, Honjo, 1979). These woody debris are identifiable as Conifer tracheids with pits and helical thickenings (Emery, Honjo, 1979, Fig. 10 *A*, *B*), which would locate their source ares in the Atlas mountains.

Whenever BOP only are present in the palynofacies, pollen absolute frequencies are never highest, and it is the littoral vegetation which shows high absolute frequencies, either saline Chenopodiaceae (16 m and around 6 m) or the humid mangrove (just below 14 m). This indicates the absence of sediments carried by rivers, while the dominant pollen transport agent is wind. Wind is therefore probably also the transport agent of BOP, and this points that BOP are residus from vegetation fires. The absence of amorphous organic matter and general low amounts of organic matter when BOP and littoral pollen predominate, suggest a somewhat oxydizing bottom environment.

Comparison with organic matter studies in other areas and periods provides more clues for understanding deposition patterns of the organic components according to their origin.

On the Russian platform (Correia, 1969, Fig. 20) during the Silurian, Upper Carboniferous and Trias, low values of organic carbon are matched by minima of spores and pollen, plant debris and almost always kerogen. But abundance of organic carbon is not always matched by all the discrete particles: in the Lower Carboniferous, the peak is accompanied by spores and pollen and plant fragments, but not by kerogen, thus suggesting its continental origin. In the Upper Jurassic, the peak is almost matched by abundant plant fragments and kerogen, but not by spores and pollen. In the Ordovician and at the Lower/Upper Cretaceous boundary, abundance of plant fragments and kerogen coincide with little spores and pollen and low or moderate amounts of organic carbon.

Organic matter horizontal distribution in the North Atlantic Cretaceous black shales (Tissot *et al.*, 1979) shows that each of the three kerogen types, marine, terrestrial and residual, has a distinct pattern, suggesting different conditions of accumulation and conservation, and also different climatic conditions on the surrounding continents.

Pollen assemblages

The well diversified pollen assemblages are presented on the Table, Figures 4 and 5. Various pollen taxa have been assigned to phytogeographical groups following the phytoclimatic zonation of West Africa (Trochain, 1940; 1980) also used by previous authors (Van Campo, 1975; Maley, 1977; Rossignol-Strick, Duzer, 1979; Caratini; Cour, 1980; Cour, Duzer, 1980). From North to South, these latitudinal vegetation zones reflect a gradient between the very dry Saharan climate to the constant humid equatorial climate (Fig. 3).

The "Mediterranean group" includes strictly Mediterranean pollen taxa, while the "Saharo-montane" one comes from the pre-Saharan southern fringe on the Atlas and the Ahaggar ranges. The "Central and North Saharan" pollen taxa have their origin in the desertic steppe which occupies areas under irregular rainfall between 0 and 150 mm. The "Sahelian group", with the highest number of pollen taxa, belongs to the dry tropical steppe under 200 to 600 mm mean annual rainfall. Taxa from the tropical savanna, which occupies areas of 600 to 1 000 mm of rain, have been assigned to the « Sudanese group". In the Sudano-Guinean and Guinean groups are included pollen taxa from deciduous and rainforests under rainfall exceeding 1 000 mm, with increase amount and duration.

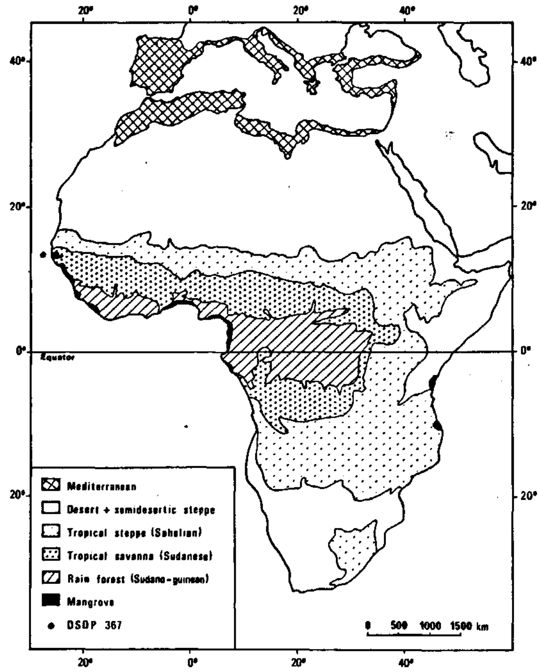

Figure 3
Phytogeographical zones of West Africa.
Zones phytogéographiques d'Afrique de l'Ouest.

The phytogeographical zonation of West Africa is also matched with various patterns of rainfall distribution. Sub-humid Mediterranean maquis, pre-Saharan, Saharo-Montane subdesertic steppes, North and Central desertic steppes have subtropical winter-spring rainfall associated with the coolest temperatures of the year. The subarid Sahelian steppe, the Sudanese sub-humid savanna and the Sudano-Guinean more humid forest have tropical summer monsoonal rainfall associated with the hottest annual temperatures.

Given the latitude of the site, the Mediterranean element is allochtonous and indicates the efficiency of transport from its source area. The tropical monsoonal element is autochtonous. Eolian pollen analysis over this part of the Atlantic (Caratini, Cour, 1980) shows that Gramineae originated in the Sahelian steppe and the Sudanese savanna, also defined by more restricted and diagnostic taxa.

The total pollen absolute frequencies (Fig. 2*B*) reflect primarily Gramineae, secondarily Cyperaceae (Fig. 4). Chenopodiaceae follow the same trends, except just above 10 m where the highest mangrove occurs. Comparison of absolute and relative frequencies (Fig. 4 and 5) points to the reality of the littoral vegetation relative frequency peaks (mangrove just above 10 m, below 14 m, Chenopodiaceae down to 8 m, just above 14 m and at 16 m).

In the present diagram (Fig. 4) the absolute frequencies of Cyperaceae, occupying either dry or marshy soils, do parallel those of the Gramineae, which suggests a common, inland grassland origin.

Coastal vegetation is represented by two steadily antagonistic facies. The mangrove with *Rhizophora* indicates humid climate and functional rivers. On the West African coast, mangrove develops in protected river estuaries but not on the wave-battered open coast

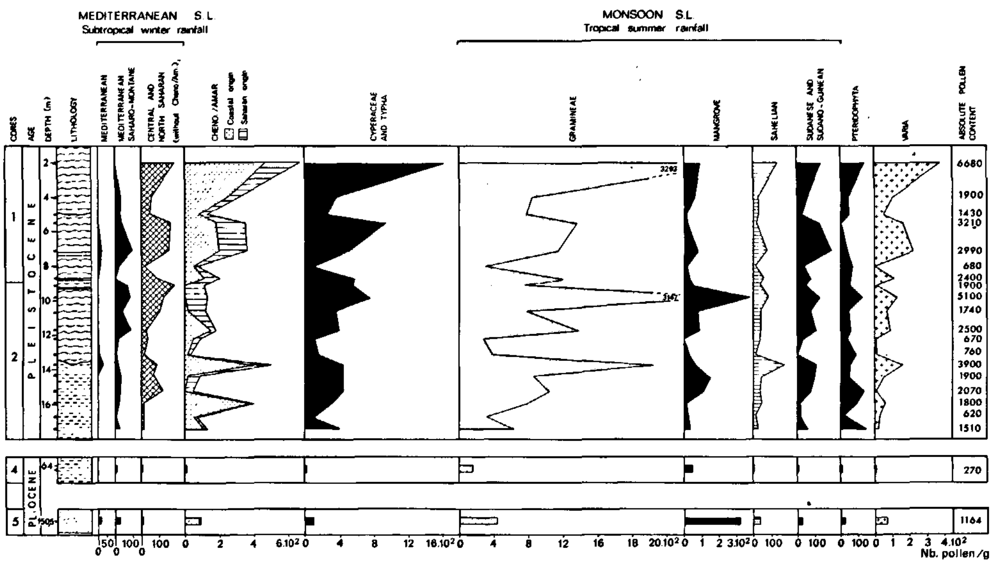

Figure 4
Pollen diagram of cores 1, 2, 4, 5, *Atlantic DSDP, site* 367; *absolute frequencies per gram of dry weight.*
Diagramme pollinique des sondages 1, 2, 4, 5, DSDP du site 367; *fréquences absolues* par gramme de poids sec.

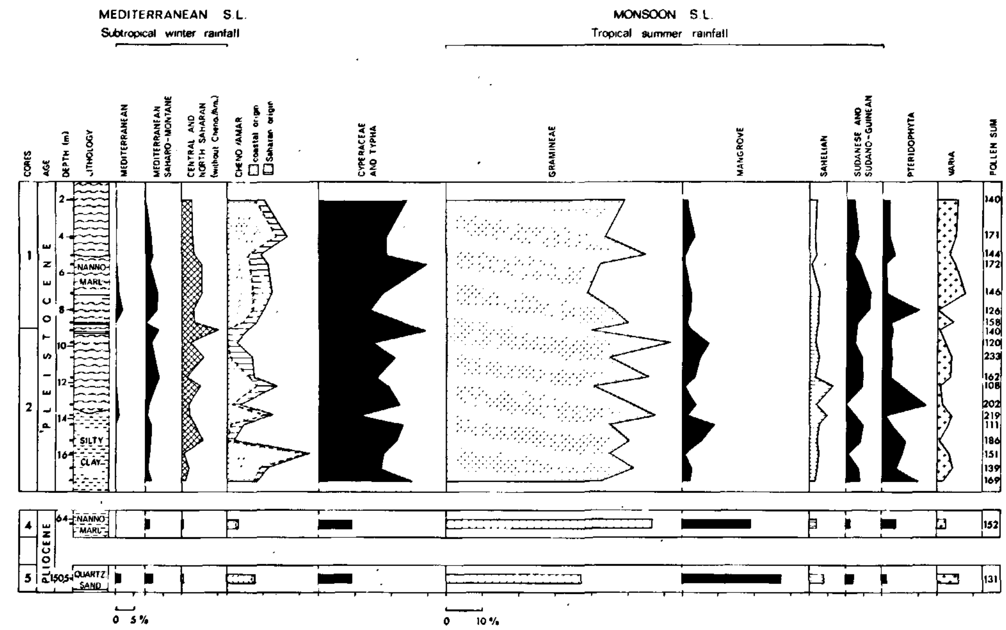

Figure 5
Pollen diagram of cores 1, 2, 4, 5, *DSDP site* 367; *relative pollen frequencies.*
Diagramme pollinique des sondages 1, 2, 4, 5, DSDP du site 367; fréquences relatives.

(Walter, 1971; Schnell, 1977). The halophyte Chenopodiaceae-Amaranthaceae colonize sebkhas and saline evaporation pans, under arid climatic conditions. However, since these saline deposits occur both inland and on the littoral, the origin of the halophyte pollen can be considered as ambiguous. In the present study, the littoral origin of the major part of the Chenopodiaceae-Amaranthaceae is documented by the comparison with pollen analysis of present-day ground dust in the North Sahara and on the Mediterranean coast at Oran (Van Campo, 1975; Cour, Duzer, 1980). The rest of this group, evaluated as equal to the Central and North Saharan diagnostic taxa, would have a Saharan origin (Rossignol-Strick, Duzer, 1979).

During the late Quaternary, the mangrove which requires fresh-water input, is correlated with high sea-level stands and humid interglacial stages, the sebkhas, with low sea-level stands and glacial arid stages (Rossignol-Strick, Duzer, 1979).

In a series of marine cores collected between 12 and 26°N along the West African coast (Agwu, 1979), the Chenopodiaceae-Amaranthaceae percentages are consistently higher during the late Würm than at the same latitude today in the ground dust pollen analysis along a North-South Saharan transect from Oran to Abidjan (Cour, Duzer, 1980).

The unexpected coincidence of the relative frequency peaks of Pteridophyte spores at 8 and 13 m, with the lowest total pollen absolute frequencies (Fig. 5 and 2 *B*), could be best explained by the high resistance of the spore membrane to destruction.

Pollen transport

Dominant fluviatile transport of pollen to the sea, for instance by the Saloun River in Senegal, is suggested for cores 1 and 2 by the terrigenous fluviàtile origin of the intercalated sandy layers (Sarnthein, 1978) and, except at 5.5 to 7 m by the parallel curves of pollen absolute frequencies and plant fragments (Fig. 2).

In cores 4 and 5, the terrigenous eolian sandy layers indicate active eolian pollen transport, although the

Pollen geographical origin \ Depths	2.01 m	4.01	5.00	5.50	7.10	8.00	8.75	9.14	9.78	10.64	11.69	12.19	13.19	13.75	14.34	15.19	15.91	16.70	17.44	64.19	150.50
Mediterranean																					
Alnus														*1*							
Pinus					*1*								*1*	*1*							*2*
Quercus						*2*															
TOTAL					1	2							1	2							2
Pre-Saharan Mediterranean and Saharo-Montane		*3*	*2*		*5*	*2*		*5*	*2*	*6*	*6*	*2*	*2*	*1*	*1*	*2*	*2*	*1*		*1*	*1*
Artemisia																					*1*
Cupressaceae			1	2		2						1			1	1		1	3	1	2
TOTAL		3	3	2	5	4		5	2	6	6	3	2	1	2	3	2	1	3	2	3
Central and North Saharan																					
× Chenopodiaceae/Amaranthaceae	14	28	13	19	18	13	13	8	3	16	12	15	7	28	5	4	34	16	15	5	10
× Compositae liguliflorae	3									1			2	1						1	
× Cruciferae						*2*								2					1		
● *Echium*	*1*	*5*	*5*	*9*	*8*	*2*	*6*	*12*	*3*	*12*	*2*	*4*	*2*	*2*	*4*	*10*	*1*	*3*	*1*		*1*
Ephedra								*2*				*1*									
● *Fagonia*										*1*											
● *Plantago*												*1*				*1*					
× Urticaceae	18	33	18	28	26	17	19	22	6	30	14	21	11	33	9	15	35	19	17	6	11
TOTAL	69	75	79	73	57	58	79	56	74	105	90	44	104	126	50	94	68	72	72	86	49
Gramineae	32	31	25	50	26	17	36	41	17	48	25	20	45	24	26	38	27	24	44	14	12
× Cyperaceae																					
× *Typha*	*2*	*1*	*2*	*1*		*1*	*2*		*1*	*1*	*1*	*1*		*1*		*2*					
TOTAL	34	32	27	51	26	18	38	41	18	49	26	21	45	25	26	40	27	24	44	14	12
Tropical humid																					
Pteridophytes	3	4	5		2	13	4	4	3	6	4	6	24	3	3	12	8	5	17	6	2
Sahelian																					
Acacia												*1*		*2*							
Barleria		*1*													*1*						
Blepharis																	*1*				
Boscia							*1*														
Capparis					*1*																
Cissus															*1*						
Commiphora						*2*				*1*				*1*							
Compositae tubuliflorae	2	1	1		1	1	1	2	1	2	1	1		3		1	2	2	2	2	1
Euphorbia			*1*		*1*			*1*	*1*	*2*				*1*							*1*
Gomphrena															*1*						
Holiotropium														*2*							
Hyphaene		*1*									*1*										*1*
Ipomoea					*1*																
Maerua	*1*			*1*								*3*		*1*							
Papilionoideae							1														1
Phyllanthus			*1*																		
Phoenix												*1*	*2*				*1*				
Salix																		*1*			
Salvadora persica							*1*					*1*				*2*			*1*		*1*
Tamarix										*1*	*1*		*2*								
Tribulus																*1*					
TOTAL	3	3	3	1	4	3	4	6	2	6	3	7	4	10	3	4	4	3	3	3	5

Sudanese																					
Borreria					1																
Caesalpinioideae															1					2	1
Cassia		1					1														
Celtis	1		1	3	4	1	1	2		5	4	2		3				3	2		1
Combretaceae																					
cf. *Cordia*								1													
cf. *Crudia*												2									
Lannea															1						
Polycarpea		2	2	1		1				1							1	2	1		
Sapotaceae				1											1						
Xeromphis						1															
Dodonaea				1		1			1	1											
TOTAL	1	3	3	6	5	4	2	3	1	7	4	4		3	4		1	5	3	2	2
Sudano-Guinean																		2			
Alchornea	1				2				1	1	1								1		1
cf. *Batopedina*						2													1		
Cleistanthus																			1		
Ebenaceae					1																
Elaeis guineensis		1																			
Hymenodictyon										1											
Ilex						1															
Macaranga										1				2	2	2			1		
cf. *Maesa*				1												2					
Malpighiaceae		1																			
cf. *Oligocodon*																1					
Palmae						1						1									
Peristrophe/Hypoestes							1														
cf. *Syzygium*	1	1			2		2	1	1	1	2			1							
Vernonia																2					
TOTAL	2	3		1	5	4	3	1	2	4	3	1		3	2	7			4		1
Mangrove																					
Lippia													1								
Rhizophora	2	6	1	1	4	3	2	4	9	11	6		7	4	9	10	1	4	4	29	36
TOTAL	2	6	1	1	4	3	2	4	9	11	6		8	4	9	10	1	4	4	29	36
Anthocerotales				1							1		1						1		
cf. Florschuetzia ?															1						1
Undetermined	8	9	5	8	11		7	1	3	9	5	1	2	9	2	1	5	6	1	4	7
Pollen sum	140	171	144	172	146	126	158	140	120	233	162	108	202	219	111	186	151	139	169	152	131
Undeterminable	2	14	1	5	5	10	5	16	16	22	1	10	28	6	18	24	3	2	14	21	16

Tableau

Detail of pollen counts for the core at site 367 according to source area and edaphic requirements (× cosmopolitan: • holarctic).

Résultats palynologiques du sondage DSDP au site 367. Les différents taxons sont regroupés en fonction de leur appartenance phytogéographique (× cosmopolite; • holarctique).

fluviatile input is probably still dominant. Eolian transport is due to the NE and E continental tradewinds (Harmattan), originating in the Lybian (winter) and Saharan (summer) subtropical anticyclones. During the Northern winter months they reach as far south as 8°N (surface Intertropical Front, ITF), when the monsoonal rain belt shifts to its southernmost position south of the Equator (Flohn, Struning, 1969) Surface marine current in the site area flows from the North (Canaries current) as the eastern boundary current of the subtropical gyre, diverging around the Cape Verde latitude into the westward North Equatorial Current and the south-eastward Guinea Current (Sverdrup *et al.*, 1942). The Canaries current intensified during the Last Glacial Maximum (18 000 year BP) (CLIMAP, 1976; McIntyre *et al.*, 1976), and may be regarded as a transport agent for Mediterranean pollen, together with intensified NE trade-winds.

CONCLUSION

In the Pliocene, very abundant mangrove pollen points to a quite humid tropical climate.

In the Pleistocene, the lower half of the section suggests rapidly alternating littoral conditions, humid with mangrove, arid with Chenopodiaceae. In the upper half, the arid littoral conditions persist. The inland savanna is present continously, although with fluctuations. The intense drilling disturbances preclude more precise evaluations.

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