Origin and evolution of Upper Triassic to Miocene clay-mineral associations from the eastern Algarve of Portugal

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RESUMO

Palavras-chave: Minerais argilosos — Algarve oriental

O estudo ao raio-X de sedimentos do Triásico superior ao Miocénico do Algarve oriental revelou a presença de minerais argilosos detríticos de origem continental bem como de neoformações de origem marinha. A sucessão vertical das associações mostra a existência de três ciclos evolutivos que se correlacionam com passagens transgressão-regressão controladas pela tectónica.

RÉSUMÉ

Mots-clés: Minéraux argileux — Algarve orientale

Des analyses aux rayons X de dépôts d'âge trias supérieur à miocène se trouvant à l'Algarve orientale (Portugal) témoignent la présence de minéraux argileux détritiques d'origine continentale ainsi que de néoformations d'origine marine. La succession verticale d'associations des minéraux argileux indique l'existence de trois cycles évolutionaires individuels qui donne lieu à croire à des événements transgression-régression controllés par la tectonique.

ABSTRACT

Key-words: Clay minerals — Eastern Algarve

XRD-analyses of pelitic deposits of Upper Triassic to Miocene age occuring in the eastern Algarve (Portugal), give evidence of the occurrence of detrital clay minerals of continental origin as well as of conspicuous neoformations of marine provenance. The vertical succession of clay-mineral associations indicates the existence of three distinctive evolutionary cycles which are thought to reflect tectonically controlled transgressive-regressive events.

1. INTRODUCTION

The Algarve representing the southernmost province of Portugal which to the west and to the south is bordered by the Atlantic Ocean and to the east is delimited by the Rio Guadiana, during the Mesozoic and the Cenozoic was part of an E-W trending marginal trough south of the Iberian Variscides. From the uppermost Triassic to the Quaternary this depression forming a connection between the Betic Trough in the east and the Lusitanian Trough of central Portugal in the north, was filled up with deposits of continental and of marine origin reflecting more or less prononced sea-level fluctuations.

During the last 10 years the Algarve has been the subject of detailed interdisciplinary investigations on the anthropogenetic influence on the groundwater budget as well as on the resulting effects on the evolution of soils and on agriculture. Recent hydrogeological and hydrochemical studies contributed to a comprehensive knowledge of the groundwater provinces occurring within the subsurface of the eastern Algarve as well as of the groundwater discharge and recharge in this region (GONÇALVES, 1982; LOUREIRO, 1983; SILVA, 1984; ALMEIDA, 1985).

Hydrochemical data from the above area of study in general suggest a lateral infiltration of seawater in coastal regions due to an intensified groundwater discharge for agricultural and domestic use which exceeds the recharge by infiltrating meteoric water, because of a low rainfall rate in this semiarid mediterranean climate, and because of the predominating moderate to poor permeability of the soils covering the Mesozoic and Cenozoic rocks (KELLNER *et al.* 1986a, 1986b). The locally increased salinity of the groundwater in the north of the coastal plain (KELLNER, 1983; LIEBERMANN, 1983), however, seems not or only partially to be due to a marine infiltration. In these areas the high concentration of ions within the groundwater (VAN BEERS *et al.*, 1981; COSTA, 1983; COSTA *et al.*, 1985) is thought to originate from the subsurface sediments forming the aquifers.

In order to increase information on the depositional environments of these strata as well as on the provenance of the clastic detritus and on the paleoclimatic conditions, samples from clayey and marly intercalations within the stratigraphic sequence of Upper Triassic to Miocene age

(fig. 1) which mainly consists of limestones, were studied with respect to the composition of the clay-mineral associations. Further investigations aiming at an evaluation of the relation between the ion concentration in some groundwater provinces and the mineralogical composition of the source rocks, have recently been completed and will be published separately (KELLNER *et al. in prep.*). These studies have been carried out within the scope of IFP 1671 (Interdisziplinäres Forschungsprojekt, Technische Universität Berlin, F. R. Germany: «Künstliche Grundwasseranreicherung in Kluftwasser leitern in semiaridien Klimata und ihre Auswirkung in landwirtschaftlicher, bodenstruktureller und sozioökonomischer Hinsicht am Beispiel Südportugal»).

2. STRATIGRAPHIC FRAMEWORK

The sedimentary succesion of Mesozoic and Cenozoic age unconformably over lies folded slates with intercalated graywackes and sandstones which were initially attributed to the Dinantian (Lower Carboniferous) Kulm facies (ROEMER, 1876). According to recent studies (ROCHA, 1976), however, an? Upper Namurian to Westphalian age is presumed. Regional distribution and changing thickness of individual lithofacies within the overlying stratigraphic sequence were largely controlled by synsedimentary tectonic movements which are thought to have been related to the gradual uplifting of the low-grade metamorphic Paleozoic basement rocks of the Iberian Meseta in the north (PRATSCH, 1958; MARQUES, 1983). The influence of tectonism on deposition increased towards the south, where the Mesozoic to Cenozoic sedimentary succession attains its maximum thickness. During the Upper Cretaceous and the Lower Tertiary these movements locally were accompanied by alkaline, mainly basaltic magmatism (PRATSCH, 1958).

In the study area Mesozoic deposition started during the late Triassic (fig. 2) with an accumulation of continental conglomerates and sandstones (20-60 m) occasionally containing clayey beds which form the basal part of the Grés de Silves of P. CHOFFAT (1887: Upper Triassic-Lower Liassic; PRATSCH, 1958: 50-200 m). These strata grade upwards into partially sandy claystones (< 80 m) with several marly intercalations indicating a gradual transgression of the sea. The Triassic portion of the Grés de Silves, the thickness
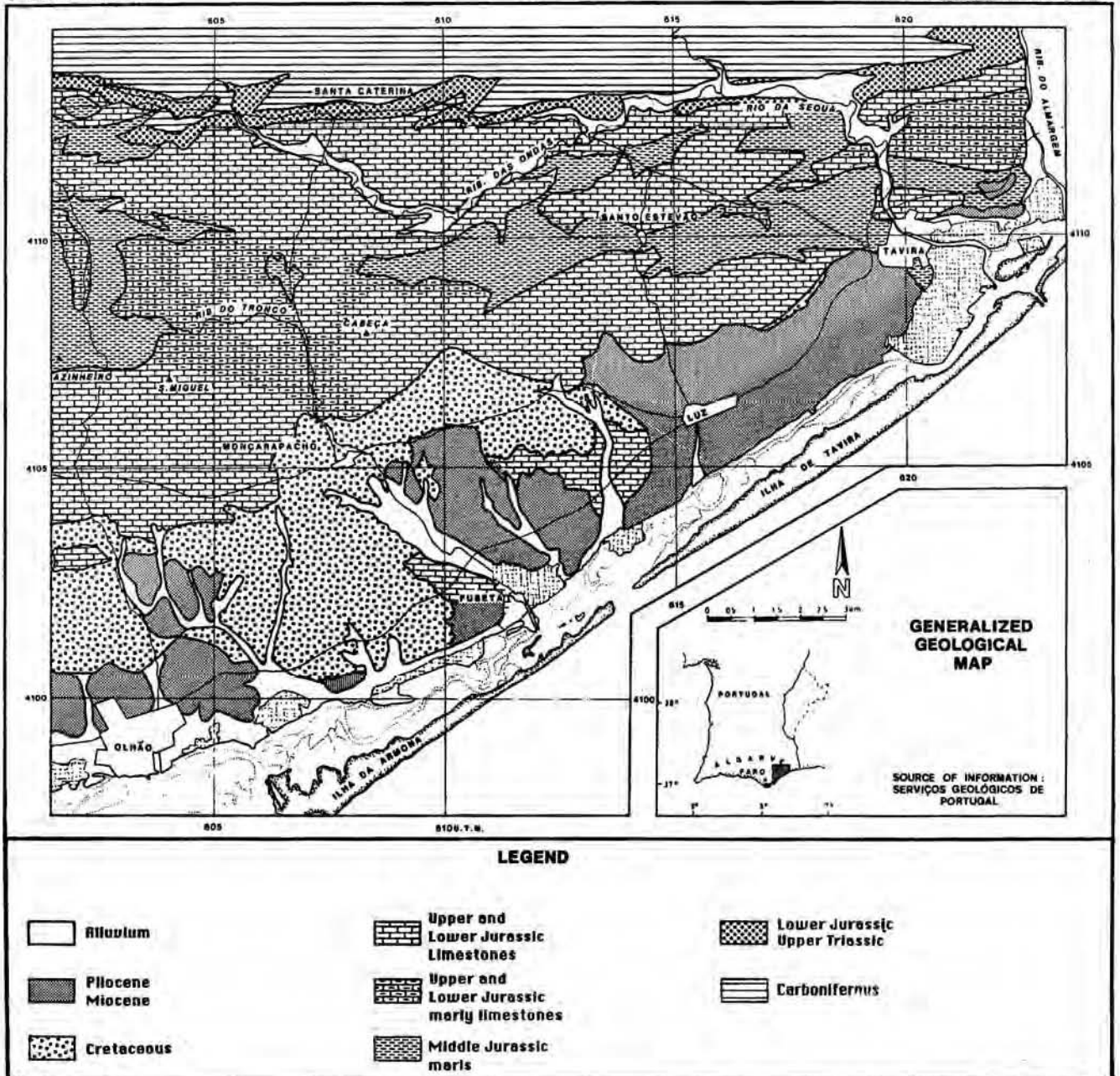
LEGEND

☐ Alluvium	▦ Upper and Lower Jurassic Limestones	▦ Lower Jurassic Upper Triassic
▨ Pliocene Miocene	▦ Upper and Lower Jurassic marly limestones	▤ Carboniferous
⠿ Cretaceous	▦ Middle Jurassic marls	

Fig. 1 — Generalized geological map of the study area

of which is assumed to vary from 30 to 130 m, locally terminates with small-and large-scale cross-stratified marine sandstones (<25 m). During the Lower Liassic sediments, which attain a tickness of 20 to 60 m and which reflect a continuating transgression, were deposited. A definite differentiation between the Triassic and the Liassic portion of the sequence, however, is difficult, because index fossils are missing. The strata of Hettangian age consist of brown fossiliferous marls (<8 m) and of grey to yellow dolomites (<8 m). The overlying Sinemurian succession is made up of varicoloured claystones and marls (<50 m) occasionally containing gypsum and halite beds, which document repeated high salinity conditions due to an intense evaporation. The spatial distribution of these precipitations suggest a tectonically originated division of the sedimentary environment into several more or less isolated depressions which are thought to have been separated by swells.

Comparable regional variations of the facies pattern also occur within the stratigraphic sequence of Pliensbachian (Upper Liassic) to Callovian (upper Dogger) age, which has a thickness of 150 to 480 m (SERVIÇOS GEOLÓGICOS PORTUGAL, 1984, 1986) in the area of study (fig. 2) and which documents prevailing marine conditions. The Pliensbachian to Aalenian (Lower Dogger) strata predominantly consist of dolomites occasionally containing marly and oolithic limestone beds. These sediments grade upwards into partially oolithic limestones representing the late Aalenian. During the Bajocian grey locally silicified limestones with several marly intercalations were accumulated again (90-170 m). The latter as well as the grey limestones and dolomites of the overlying Bathonian sequence (<30 m) repeatedly contain oolithic beds and reefal complexes documenting a littoral to shallow shelf environment. The succession of Callovian age (70-140 m) is made up of yellow
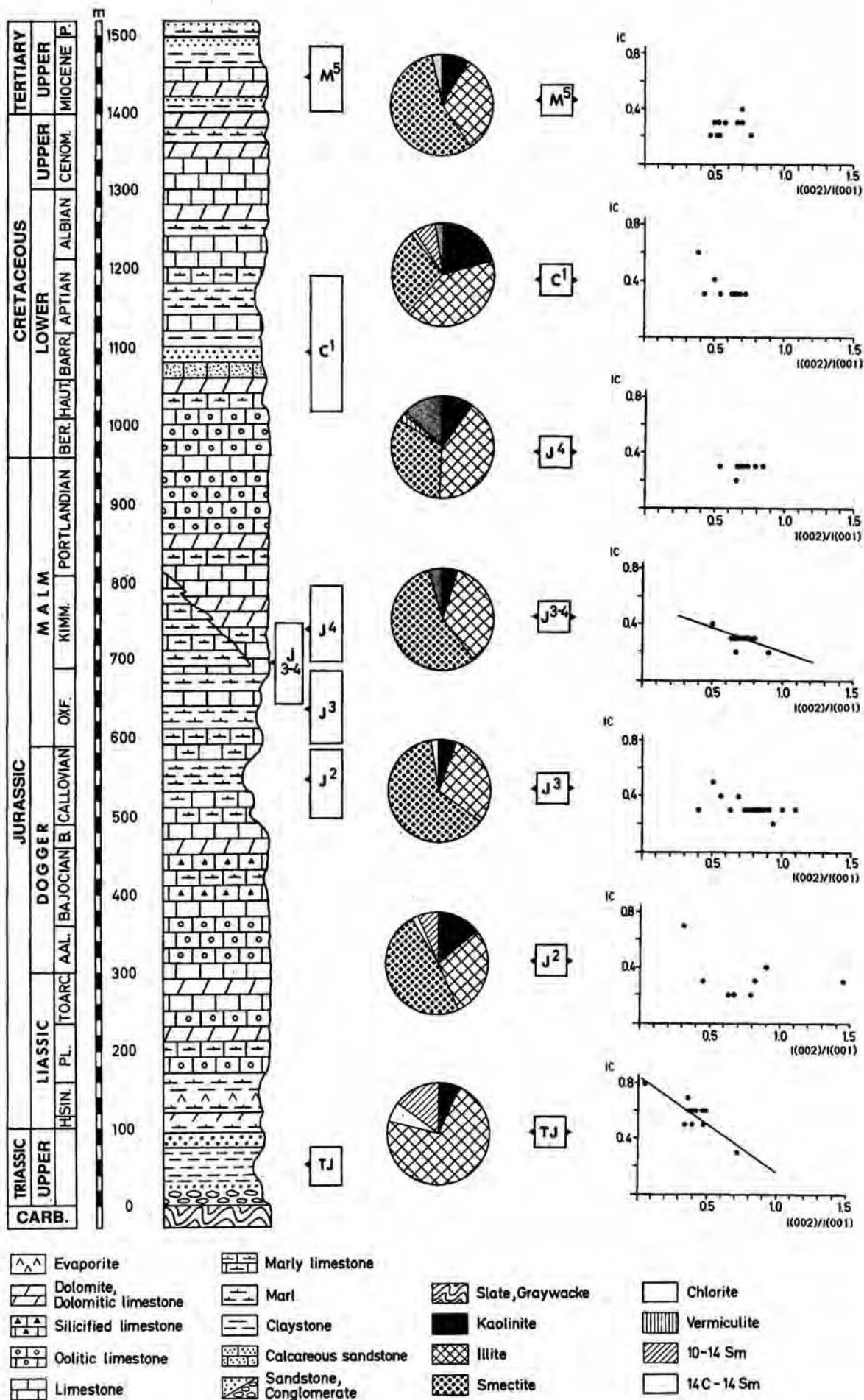
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Fig. 2 — Composite stratigraphic section showing the lithology, the composition of the clay-mineral subassociations (pie diagrams) as well as the illite crystallinity (IC) and the I(002)/I(001)-ratio (scatter diagrams) of the sedimentary succession of Upper Triassic to Miocene age

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to brown fossiliferous marls with grey limestone beds. The strata in the upper part of this stratigraphic sequence are attributed to a regression, beginning during the Upper Callovian and persisting during the Lower Oxfordian.

The deposits of the Middle and Upper Oxfordian (Lower Malm) consist of yellow and brown alternating marls and fossiliferous limestones. They accumulated after a new transgression of the sea and disconformably overlie the Callovian strata (PRATSCH, 1958; MARQUES, 1983). This sucession (fig. 2) which altogether attains a maximum thickness of 125 m terminates with oolithic limestones. They locally interfinger with a breccia containing reworked limestone fragments. These sediments indicate a second, however, minor regression (PRATSCH, 1958; MARQUES, 1983; SERVIÇOS GEOLÓGICOS PORTUGAL, 1984, 1986).

A third stratigraphic sequence which documents an initial transgression and a subsequent regression of the sea, comprises the Middle Malm to Lower Cretaceous shallow marine sediments of Kimmeridgian (100-150 m), Portlandian (180-500 m) and Berriasian to Barremian age (PRATSCH, 1958; MARQUES, 1983; SERVIÇOS GEOLÓGICOS PORTUGAL 1984, 1986: 150-250 m). The Kimmeridgian sequence (fig. 2) comprises interbedded marls and grey limestones in its lower portion (Lower Kimmeridgian), whereas in the upper portion grey dolomitic limestones with oolithic beds, dolomites as well as occasional marls, red sandstones and conglomerates occur (Upper Kimmeridgian). During the Portlandian grey and brown fossiliferous dolomitic limestones and varicoloured marls were deposited. The basal part of the Lower Cretaceous succession is made up of oolithic limestones (Berriasian). These are overlain by dolomites locally interfingering with white marls and chalky limestones (Hauterivian). Sediments of Valanginian age are not exposed in the study area. The uppermost regressive part of this stratigraphic sequence (Barremian) is formed by sandy limestones which alternate with claystones, red sandstones and conglomerates (SERVIÇOS GEOLÓGICOS PORTUGAL, 1984, 1986).

Another sedimentary succession reflecting a transgressive-regressive event, accumulated in parts of the eastern Algarve during the Aptian to Cenomanian (PRATSCH, 1958; SERVIÇOS GEOLÓGICOS PORTUGAL, 1986). In the area of study, however, only deposits of Aptian to Albian age (300-500 m) are exposed. They consist of partially marly or chalky, detrital limestones (fig. 2).

After the period of intense tectonism during the Upper Cretaceous and the Lower Tertiary a last minor transgression flooded the Algarve during the Miocene. The stratigraphic sequence which accumulated during this invasion of the sea (fig. 2), overlie sediments of Jurassic and Cretaceous age with an angular unconformity. These deposits, the thickness of which varies from 70 to 150 m, comprise interbedded grey massive limestones and dolomites, marls, grey partially silty claystones, sandstones as well as conglomerates. The spatial distribution and the rapidly changing thickness of individual lithofacies suggest pronounced environmental variations due to synsedimentary tectonic movements.

3. METHODOLOGY

The clay-mineral associations of 78 surface samples from seven mappable units, which occur within the above stratigraphic sequence of Upper Triassic to Miocene age and which locally contain considerable amounts of pelitic strata, have been determined from oriented mounts of the < 2 um-fraction by X-ray diffraction (XRD). From each of the samples examined, three XRD-traces were produced: (1) after air-drying, (2) after glycolation for 48 hours and (3) after heating to 550°C for four hours. For the identification and semi-quantitative evaluation of the clay-mineral composition from the diffractometer traces, the modified methods of G. DUNOYER DE SEGONZAC (1969) and J. THOREZ (1975, 1976) were used.

The clay-mineral assemblage from the eastern Algarve is characterized by the occurrence of minerals from the kaolinite (K), illite (I), chlorite (C), smectite (Sm) and vermiculite (V) groups. Additionally randomly interstratified illite-smectite (10-14Sm) as well as regularly and randomly interstratified chlorite-smectite (14C-14Sm) appear. The fundamentals for their identification and description have been comprehensively described by J. THOREZ (1975, 1976). Regularly interstratified chlorite-smectite is referred to as corrensite (LIPPMANN, 1954). The methods of G. DUNOYER DE SEGONZAC (1969) and of J. ESQUEVIN (1969) were applied to estimate the illite crystallinity which has been measured at half of the height of the I(001) 10 Å-illite reflection above the background (acute index), and the I(002)/I(001)-ratio which has been calculated from the measured height of the secondary I(002) 5 Å-and the primary I(001) 10 Å-reflection above the background. The data of the above evaluations have been plotted in a diagram which, according to J. ESQUEVIN (1969), allows considerations about chemical variations as well as about the burial histories of the illitic minerals.

4. ABUNDANCE AND ORIGIN

Kaolinite occurring in 75 of the samples examined, attains an abundance of 1 to 56%. This clay mineral is thought to have been neoformed from hydrolysis products in a well-drained and acidic terrestrial environment. It thus indicates strong chemical weathering under warm and at least periodically humid conditions which presumably was favoured by pedogenetic processes. The changing amounts of detrital continentally derived kaolinite in the marine Mesozoic and Cenozoic deposits of the eastern Algarve (fig. 2), therefore are attributed to a seaward transportation of inherited alteration products originating from the outcropping Paleozoic rocks in the north by river systems.

Comparable to kaolinite, also illite appearing ubiquitously in the investigated sediments (3-87%), due to the predominating high crystallinity of this mineral (fig. 2, 3) suggest a terrestrial provenance (HENDRIKS, 1982). According to G. DUNOYER DE SEGONZAC (1969), the acute index of the 10 Å-illite reflection for 59 of the samples indicates epizonal metamorphism. These minerals are therefore attributed to an erosion of strata of the Carboniferous Kulm facies without important chemical alteration of the inherited products. The illite crystallinity of the other samples suggest parent rocks from an anchimetamorphic (10 samples) to diagenetic (9 samples) facies. These crystallinities, however, are thought not to be original. They are, moreover, attributed to a beginning degradation of muscovite-type illite, due to chemical alteration. The negative
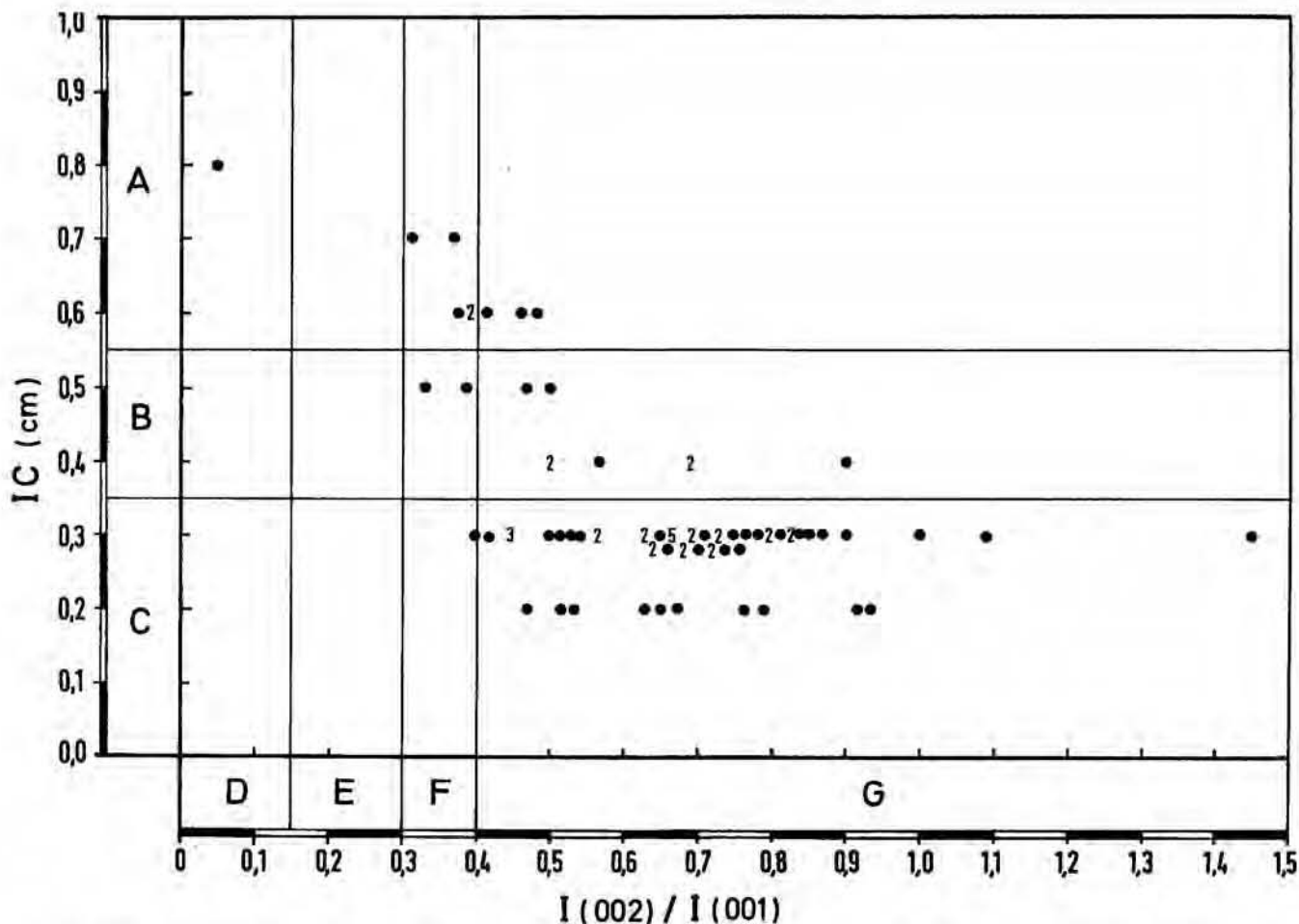
Fig. 3 — Illite crystallinity (IC) and I(002)/I(001)-ratio in the pelitic deposits investigated (ESQUEVIN 1969: A=diagenetic zone, B=anchizone, C=epizone, D=biotite, E=biotite+muscovite, F=phengite, G=muscovite). Numbers indicate the quantity of samples having an identical IC- and I(002)/I(001)-value

correlation of the I(002)/I(001)-ratios for sediments of different stratigraphic age (correlation coefficients: TJ = − 0.8320, J3-4 = − 0.6498, fig. 2) coincidingly suggest a changing $Al_2O_3/FeO + MgO$ composition of the octahedral layers (ESQUEVIN, 1969), while chemical transformation increases.

Randomly interstratified illite-smectite (fig. 2) occurring in 27 of the samples examined (2-38 %), is thought to reflect a degradation of detrital illite before deposition in a marine environment due to continental pedogenetic weathering processes. The predominance of the illite-dominated 10-(10-14Sm) mixed-layer type of J. THOREZ (1975) which appears in 17 samples, the paucity of 10-(10-14Sm) and 10-(10-14Sm)-14Sm interstratifications (7 and 3 samples respectively) as well as the lack of smectite-dominated (10-14Sm)-14Sm and (10-141Sm)-14Sm mixed-layer types, however, indicate only a rather weak alteration of illitic detritus. This might on one hand be due to the relative stability of illite against chemical weathering during pedogenesis which is higher than that of chlorite under comparable conditions. On the other hand, however, erosional processes which could have been effected by tectonic movemerts changing the paleorelief within the terrestrial areas, are supposed to have truncated or completely stripped off soils, thus interrupting illite degradation and initiating a redeposition of clay-mineral assemblages containing inhe-

rited kaolinite, illite and randomly interstratified illite-smectite as well as chlorite.

Due to the frequent association of chlorite with detrital illite and illite-dominated interstratified illite-smectite (fig. 2) indicating only subordinate chemical alteration, this clay mineral which appears in 30 of the samples investigated (2-25 %), for its majority is attributed to a continental provenance. The occurence of chlorite in srata which also contain high amounts of neoformed clay minerals of definite marine origin like smectite and corrensite, however, additionally point to an occasional chlorite formation from ion-enriched solutions in a marine environment.

Smectite (fig. 2) which occurs in 63 samples (13-93 %), is attributed to a marine neoformation in an alkaline environment with a high concentration of aluminum and silica (HENDRIKS, 1985, 1987). Marine smectite formation indicates a considerable supply of ion-enriched solutions from continental areas as products of hydrolysis. A terrestrial transformation of detrital illite into smectite by chemical weathering or pedogenetic processes is not very likely, because smectite-dominated randomly interstratified illite-smectite types reflecting an increasing degradation of this inherited mineral, are missing. Partially, however, chlorite of continental origin reacting more sensitive on chemical alteration, according to G. MILLOT (1970), might have been transformed into smectite.

Vermiculite appearing in 2 of the samples examined (11 and 15 % respectively), as well as randomly interstratified chlorite-smectite (fig. 2) occuring in 13 samples (1-5 %), could represent intermediate stages of this pathway of chlorite degradation. The latter, however, is for its majority presumed to be genetically related to the formation of corrensite, a regularly interstratified chlorite-smectite clay mineral which occurs in 17 samples (5-23 %). Corrensite which appears predominantly in strata laterally grading into gypsum- and anhydrite-bearing deposits, is thought to be a neoformation from marine environments, which, comparable to lagoons, have been protected from the open sea by swells and which must have been supersaturated due to intense evaporation (STROUHAL & HENDRIKS, 1988).

5. VERTICAL DEVELOPMENT

On order to illustrate the evolution of the clay-mineral associations in the study area, for each of the mappable units of Upper Trassic to Miocene age containing pelitic intercalations, average clay-mineral contents were calculated (Table 1, fig. 2). The vertical succession of the resulting 7 individual subassociations characterize the occurence of 3 distinctive evolutionary cycles within the stratigraphic sequence. From the bulk of data especially the changing average amounts of detrital and of neoformed clay minerals respectively reflect the control of synsedimentary tectonic movements as well as of transgressions and regressions on deposition.

The first cycle comprises the sedimentay succession of the Upper Triassic to the Oxfordian (TJ: Upper Triassic-Lower Liassic, J2: Callovian, J3: Oxfordian). The total content of clay minerals of definite detrital origin within the TJ-samples (Grés de Silves) amounts to 100%. In the pelitic strata of Callovian (J2) and Oxfordian (J3) age, however, detrital clay minerals attain an average abundance of 52%

and of 37 % respectively. Coincidingly, the amounts of illite (TJ: 73%, J2: 29%, J3: 29%), randomly interstratified illite-smectite (TJ: 15%, J2: 7%, J3: 0%) and chlorite (TJ: 6%, J2: 2%, J3: 2%) attenuate, whereas the content of neoformed smectite (TJ: 0%, J2: 48%, J3: 63%) is increasing (table 1, fig. 2). These data altogether suggest a diminishing terrestrial and a progressive marine influence on deposition from the Upper Triassic to the Upper Jurassic. The regression of the sea during the Upper Callovian and Lower Oxfordian is thought to be documented by the increased average amount of continentally derived kaolinite (TJ: 6%, J2: 14%, J3: 6%) in the J2-sediments.

For the TJ- and the J2-samples the progressive replacement of 10-(10-14Sm) by 10-(10-14Sm) and 10-(10-14Sm)-14Sm types of randomly interstratified illite- smectite additionally reflect an increasing degradation of illite (table 1) due to continuating weathering processes. The occurrence of the latter mixed-layer types together with highly crystalline illite (fig. 2) for the Callovian deposits indicates an admixture of more or less unaltered detritus (illite) to progressively degraded denudation products (randomly interstratified illite-smectite) which have been subject to terrestrial weathering already for a longer time. They are thought to be related to the randomly interstratified (10-14Sm) clay minerals occurring in the samples from the Grés de Silves (Upper Triassic-Lower Liassic), the clay-mineral subassociation of which is characterized by low illite crystallinities and illite-dominated randomly interstratified illite-smectite (table 1, fig. 2). Comparable to the Callovian sediments, the illite crystallinity also for the Oxfordian strata (J3) suggest a deposition of chemically almost unaltered clay minerals of continental origin. Randomly interstratified illite-smectite, however, is missing possibly due to an extensive erosion of (10-14Sm)-bearing weathering products after the regression of the sea during the Upper Callovian and Lower Oxfordian.

In contrast to the underlying first cycle, the units J3-4 (Upper Oxfordian-Lower Kimmeridgian), J4 (Kimmeridgian)

TABLE 1

A) Average amounts of clay minerals within the sedimentary succession of Upper Triassic to Miocene age (n = number of samples, K = kaolinite, I = illite, Sm = smectite, C = chlorite, V = vermiculite, 10-14Sm = randomly interstratified illite-smectite, 14C-14Sm = randomly and regularly interstratified chlorite-smectite. B) Abundance of specific mixed-layer types within the stratigraphic sequence investigated ([1] = 10-(10-14Sm), [2] = 10-(10-14Sm), [3] = 10-(10-14Sm)-14Sm, [4] = randomly interstratified chlorite-smectite, [5] = regularly interstratified corrensite-type chlorite-smectite)

	n	K	I	Sm	C	V	10-14Sm	14C-14Sm	1)	2)	3)	4)	5)
		A)						in %	B)		number of samples		
M5	11	9	31	56	-	-	-	4	-	-	-	9	2
C1	10	21	41	27	1	-	7	3	3	2	2	2	2
J4	11	10	41	33	-	2	1	13	2	-	-	1	10
J3-4	10	5	34	56	-	-	-	5	1	-	-	-	3
J3	16	6	29	63	2	-	-	-	-	-	-	-	-
J2	9	14	29	48	2	-	7	-	2	3	1	-	-
TJ	11	6	73	-	6	-	15	-	9	2	-	-	-

and C1 (Berriasian-Barremian) which form the second cycle within the stratigraphic sequence investigated, are characterized by an upward growing content of detrital clay minerals (J3-4: 39%, J4: 54%, C1: 70%). The average abundances of kaolinite (J3-4: 5%, J4: 10%, C1: 21%), illite (J3-4: 34%, J4: 41%, C1: 41%), randomly interstratified illite-smectite (J3-4: 0%, J4: 1%, C1: 7%) and chlorite (J3-4: 0%, J4: 0%, C1: 1%) coincindingly gradually increase (Table 1, fig. 2). The above clay-mineral subassociations are attributed to a stepwise regression of the sea after a rapid and extensive initial transgression. Vermiculite (2%) occurring in two of the J4-samples examined from this cycle, is thought to indicate a degradation of chlorite due to terrestrial weathering.

The growing continental influence on deposition is also reflected by the diminishing content of neoformed smectite (J3-4: 56%, J4: 33%, C1: 27%). Especially typifying for the clay-mineral subassociations of the second cycle (Table 1, fig. 2), however, is the abundance of regularly (corrensite-type) and of randomly interstratified chlorite-smectite (3-10-2 and 0-1-2 samples respectively) which are supposed to represent a neoformation from a supersaturated marginal marine lagoonal environment. The average contents of interstratified chlorite-smectite (J3-4: 5%, J4: 13%, C1: 3%) for the Kimmeridgian strata suggest maximum evaporation within these protected embayments.

As for the J3-deposits (Oxfordian) forming the uppermost part of the underlying first cycle, the subordinate importance of randomly interstratified illite-smectite in the transgressive Upper Oxfordian to Lower Kimmeridgian sediments (J3-4: 1 sample) indicate an intense denudation of (10-14Sm)-bearing paleosols in terrestrial areas in connection with the previous minor regression during the Upper Oxfordian. In the Upper Oxfordian to Barremian deposits (J3-4 and C1) illite dominated *10*-(10-14Sm) randomly interstratified illite-smectite is progressively replaced by 10-(10-14Sm) and 10-(10-14Sm)-14Sm mixed-layer types (Table 1) which documents an increasing degradation due to continental chemical weathering. Again, however, illite with a high crystallinity reflecting quick erosion and weak chemical alteration (fig. 2), suggests a continuous admixture of unaltered detritus.

Comparable to basal J3-4-subassociation from the second cycle, the Miocene (M5) clay-mineral assemblage, which is attributed to a third, however, incompletely preserved cycle (Table 1, fig. 2) and which also has been deposited after an extensive transgression, is characterized by a low average amount of clay minerals of definite detrital origin (40%). In contrast to the C1-samples, however, the abundance of kaolinite as well as of highly crystalline illite (9% and 31% respectively) has distinctly decreased. Similar to the Oxfordian strata (J3), randomly interstratified illite-smectite is missing which probably is due to a pre-Miocene erosion after the regression of the sea. Additionally, chlorite is absent in the Miocene sediments. The majority of the neoformed clay minerals are smectites (56%). Whereas their abundance in comprarison to the pelitic deposits of Cretaceous age has been doubled, the amount of interstratified chlorite-smectite has not changed (4%). However, only 2 of the 11 samples examined, contain corrensite-type regular interstratifications. In the remaining 9 samples exclusively randomly interstratified chlorite-smectite appears. Although the latter type is predominating, the occurrence of corrensite for the entirety of interstratified chlorite-smectite clay minerals in the Miocene sedimentary succession is thought to suggest a marine neoformation.

6. CONCLUSIONS

The clay-mineral associations of the seven mappable units studied from the eastern Algarve, for the stratigraphic sequence of Upper Triassic to Miocene age document the occurrence of detrital clay minerals of definite continental origin coexisting with conspicuous neoformations of marine provenance.

The group of detrital clay minerals consists of: (1) kaolinite, (2) illite, (3) randomly interstratified illite-smectite, (4) chlorite, (5) vermiculite and (6) randomly interstratified chlorite-smectite. These minerals altogether suggest only subordinate chemical alteration processes in the terrestrial areas adjacent to the marine sedimentary basins due to prevailing hot and semiarid climatic conditions.

Kaolinite represents a continental neoformation from hydrolysis products. Illite which is characterized by a predominating high crystallinity, as well as chlorite are inherited from Paleozoic basement rocks. Randomly interstratified illite-smectite generally being illite-dominated, is a product of illite degradation, whereas vermiculite and partially also randomly interstratified chlorite-smectite are attributed to chlorite degradation.

The group of neoformed clay minerals comprises: (1) smectite indicating alkaline marine environments, as well as (2) randomly and regularly (corrensite-type) interstratified chlorite-smectite pointing to more or less evaporitic lagoonal environments. These minerals indicate a constant supply of continentally derived ion-enriched solutions resulting from hydrolysis.

The vertical succession of clay-mineral associations characterizes three distinctive evolutionary cycles:

(1) The gradual replacement of detrital clay minerals by smectite for the first cycle comprising the TJ-(Upper Triassic-Lower Liassic), J2- (Callovian) and J3- deposits (Oxfordian), documénts an attenuating terrestrial and a progressive marine influence on sedimentation which terminates with the regression of the sea during the Upper Oxfordian. The relatively high kaolinite content in the J2- strata is attributed to the previous regression of Upper Callovian to Lower Oxfordian age.

(2) The decreasing amount of neoformed and the increasing content of inherited clay minerals for the second cycle which is made up the J3-4- (Upper Oxfordian-Lower Kimmeridgian), J4- (Kimmeridgian) and C1-deposits (Berriasian-Barremian), suggest a growing supply of pelitic detritus of continental origin due to a stepwise regression of the sea during the Kimmeridgian to Barremian after a rapid transgression of Upper Oxfordian to Lower Kimmeridgian age.

(3) Comparable to unit J3-4 forming the basal portion of the second cycle, the low amount of terrestrial detrital clay minerals and the high content of marine neoformations for the M5-sediments (Miocene) which are attributed to a third, only partially preserved cycle, indicate a diminished input of continental denudation products after another transgression of the sea.

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