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CALICHE CRUSTS IN ISLANDS OF SOUTHERN AND EASTERN AEGEAN AND OF SOUTHERN IONIAN SEA

F. POMONI-PAPAIOANNOY, A. GALEOS

ABSTRACT

Quaternary caliche crusts produced by pedogenic accumulation of calcium carbonate material have developed in or on pre-existing carbonate formations, in several islands of Southern - Eastern Aegean and of Southern Ionian Sea. The weathering profiles studied exhibit a range of caliche structures including rhizoconcretionary, laminar, massive, glaebular and pisolitic types. The above microfacies present different calichification maturity stages taking place in a semi-arid to arid environment during post-Pliocene to the Recent. The calcium carbonate necessary for calichification has been provided through an in-situ transformation of the host carbonate rocks. Analogous features may well be preserved in ancient sedimentary sequences providing valuable information for palaeoenvironment reconstruction.

ΣΥΝΟΨΗ

Τεταρτογενείς κρούστες caliche, που αντιπροσωπεύουν το αποτέλεσμα πεδογενετικής συγκέντρωσης ασβεστολιθικού υλικού έχουν αναπτυχθεί στην επιφάνεια ή μέσα σε προϋπάρχοντες ανθρακικούς σχηματισμούς, σε διάφορα νησιά του Νοτίου και Ανατολικού Αιγαίου και του Νοτίου Ιονίου. Τα μελετηθέντα "προφίλ" εξαλλοίωσης εμφανίζουν ένα φάσμα ιστών caliche, που περιλαμβάνουν ριζογενείς, λαμινώδεις, συμπαγείς, θρομβώδεις και πισολιθικούς τύπους.

Οι ανωτέρω μικροφάσεις αντιπροσωπεύουν διάφορα στάδια ωρίμανσης στη διεργασία της calichification, που έλαβε χώρα σε ημί-ξηρό προς ξηρό περιβάλλον μετά το Πλειόκαινο και μέχρι σήμερα. Το αναγκαίο για την calichification ανθρακικό ασβέστιο έχει μάλλον προκύψει μέσω μιας in-situ μετατροπής των ξενιστών ανθρακικών πετρωμάτων. Ανάλογα χαρακτηριστικά είναι δυνατόν να διατηρηθούν σε παλαιές ιζηματογενείς ακολουθίες προσφέροντας πολύτιμες πληροφορίες για την αναδιάρθρωση του παλαιοπεριβάλλοντος.

* Dr. F. POMONI - PAPAIOANNOU and A. GALEOS M.Sc.
I.G.M.E., 70 MESSOGHION St. 115 27 ATHENS

* ΠΕΔΟΓΕΝΕΤΙΚΕΣ ΚΡΟΥΣΤΕΣ (CALICHE) ΣΕ ΝΗΣΙΑ ΤΟΥ ΝΟΤΙΟΥ ΚΑΙ ΑΝΑΤΟΛΙΚΟΥ ΑΙΓΑΙΟΥ ΚΑΙ ΤΟΥ ΝΟΤΙΟΥ ΙΟΝΙΟΥ.

INTRODUCTION

The determination of the diagenetic environment has been proved to be of significant importance equal to the knowledge of the depositional environment since it provides much information concerning the chemistry of the reacting with the host sediments interstitial fluids, responsible for the mineralogical as well as for the textural and structural diagenetic modifications of the rocks. Between the several diagenetic environments, the vadose zone is one of the most intensively studied. However, only during the last decade attention has been paid to the formation of the uppermost crusts on constantly or periodically exposed sediments and rocks in semi-arid to arid climates. The formation of these crusts is a pedologic phenomenon, including all the physicochemical and biological processes affecting the substrates (FREYTET and PLAZIAT, 1982). The facies produced by pedologic alteration of the substrates are included under the term "caliche" which is synonymous with "calcrete". According to COUDIE's (1973) genetic definition caliche represent "terrestrial materials composed dominantly but not exclusively of $CaCO_3$, which occur in states ranging from nodular and powdery to highly indurated and result mainly by displacive and/or replacive introduction of vadose carbonate into greater or lesser quantities of soil, rock or sediment within a soil profile" (From WATTS, 1980; p. 663). Later on several modified definitions have been proposed, one of the most interesting by ESTEBAN & KLAPPA (1983), who defined caliche as "a vertically zoned sub-horizontal to horizontal carbonate deposits developed normally with four rock types: the massive-chalky caliche, the nodular-crumbly caliche, the platy or sheet-like caliche and the compact crust or hard pan whose position and development in vertical and lateral means is higly variable" (p. 15).

Calichification is a diagenetic process which modifies the original sedimentary features and produces new textures and structures. For progressive calichification a prolonged subaerial exposure of the rocks with little or no deposition is necessary, because the most mature pedogenetic profiles need time (probably thousands of years) to form. The calichification process yields characteristic features such as clotted micrite, rhizoliths, glaebules e.t.c. and is not controlled by special depositional and lithological factors of the host sediment. The intensity, form, type and thickness of the formed caliche depends mainly on the mechanical stability of the host rocks, since development of a caliche profile requires a stable substrate sufficiently long exposed for pedogenic processes to operate. Permeability and calcium carbonate content of the host material can influence the rate of caliche formation (ESTEBAN & KLAPPA, 1983). Moreover several other factors including climate, topography, sediment accretion rate, plant and animal populations and time may also control the calichification rate (WATTS, 1980; FREYTET & PLAZIAT, 1982; ESTEBAN & KLAPPA, 1983). However, the most important factor is the $CaCO_3$ source, because for calichification an excessive amount of $CaCO_3$ is necessary. Aeolian input of carbonate dust is considered to be the main source (GOUDIE, 1973) while other sources such as weathering of calcareous parent material and capillary updraw from grounwater may also provide $CaCO_3$ (WRIGHT, 1982).

Being a product of subaerial weathering, caliche in a sequence of marine carbonates provides valuable information for the paleogeographic-paleoclimatic conditions interpretation as well as for the diagenetic evolution. Due to lithification prior to erosion or renewed sedimentation, caliche profiles are well preserved avoiding the removing or mix of the soil with new sediments (ESTEBAN & KLAPPA, 1983). Many studies exist concerning both ancient and Quaternary caliche deposits proving its great importance as an indicator of emergence and unconformity (STEINEN, 1974; ESTEBAN, 1976; HARRISON & STEINEN, 1978; ADAMS, 1980; ARAKEL, 1982 e.t.c.).

However most of the studies deal with pedogenic caliche while knowledge of caliche formed in non-pedogenic environments namely at depths well below the modern soil profiles at the deep vadose-phreatic zone interface is poor (SEMENIUK & MEAGHER, 1981). The non-pedogenic caliche are formed by precipitation of $CaCO_3$ caused by plants utilizing vadose and phreatic waters. Thus, in the so-called "groundwater caliche", vegetation is an important factor that controls its formation.

In this paper the sections on Microscopical Description and Interpretation are written by F. Pomoni - Papaioannou whereas the sections on Geological Setting and Study Areas are written by A. Galeos.

GEOLOGICAL SETTING

During the 1:50.000 geological mapping of several islands in Southern and Eastern Aegean as well as in Southern Ionian (sheets Astypalea, 1986; Sirna, Antikithira, in press) extensive thick and massive caliche crusts have often been observed in or on pre-existing carbonate formations. These crusts usually cover smooth morphologic surfaces and in places reach an altitude of the order of 300 m. Crusts in high altitudes have a small extension and are found as weathering relics, while in low altitudes they present a wide extension. The crusts are very hard and compact, and have a reddish-yellow reddish to grey yellowish tint. Commonly they cement carbonate breccia, as well as grainstone formations. Micropalaeontological determinations proved that they began to form from Upper Pliocene and continue to form till now. Sampling has been carried out by A. GALEOS and E. DRANDAKI (Geologists of I.G.M.E.) during the geological mapping of the island Sirna, Astipalea, Antikithira and the surrounding islets.

STUDY AREAS

Isl. Kounoupi (Fig. 1)

It is situated at the eastern part of Astipalea. Remnants of crusts have been observed on the Upper Cretaceous (Senonian-Maastrichtian) dolomitized limestones with rudists up to an altitude of about 40 m a.s.l. (Schem. Sect. No 1). These are greyish-black, thick-bedded to unbedded, neritic, bituminous carbonate formations and belong to the Tripolis isopic zone.

Microscopical Description

The host rock is a greyish dolomite overlain or surrounded by reddish-brownish lime crusts, with irregular and sharp contact (PL. I, Fig. 1). Microscopical examination revealed a dolopseudosparite consisting of xenomorphic crystals of size in the range of 70-120 μm. The dolopseudosparite is cross-cut by a system of tubular structures consisting of straight or slightly sinuous cylindrical tubules with a fairly constant width up to 1 mm. The tubules are commonly branched with significantly decreased distally diameters (PL. I, Fig. 2). The tubule walls consist of tangentially orientated elongated calcite needles (needle-fibre calcite). The needles are only a few microns wide and up to several hundreds of microns long.

The overlying or surrounding crusts consist of alternations of well-developed laminated spherulitic crusts, the interspaces of which have been occupied by glaebular micritic matrix (PL. I, Fig. 3,4). Glaebules include grains such as peloids, ooids, coated grains, pisoids e.t.c. The crusts exhibit a botryoidal way of growth and are composed of closely connected spherical to ellipsoidal bodies consisting of bundles of calcite fibres (PL. I, Fig. 3), often displaying a radial internal and a relic concentric structure (PL. I, Fig. 4). The rays of each spherulite extend from the centre of the grain-commonly occupied by a micritic nucleus-to the grain surface and their length ranges from 200 μm to 700 μm. The long axis of the elliptical spherulites is commonly perpendicular to the stratification (PL. I, Fig. 4). Aligned micritic inclusions corresponding to preexisting growth surfaces underline a relic concentric-zoned structure (PL. I, Fig. 3). The spherulitic calcite fibres are slightly yellowish, non-pleochroic, length-slow and commonly they show blunt terminations. Dog-teeth cement rims either develop on the spherulitic crusts or surround glaebules and other components.

The glaebular matrix that occupies the between the botryoidal spherulitic crusts interspace is reddish-brownish and is characterized by a clotted texture, being composed by fairly coalescing glaebules of variable size. Small relics of the host material are included in the glaebules and are clearly observed in the coarser ones. The cementing material has the same composition and texture with that of the glaebules. Relic fragments of the host dolomitic rocks are in places preserved through alteration while in some pisoids they form the nucleus. A texture consisting of ellipsoidal to subrounded approximately equidimentional voids, either empty or partially to wholly filled with sparry calcite, separated by a network of interconnecting sheaths of micrite (needle-fibre sheaths) was observed (PL. II. Fig. 1). This texture is similar to the "alveolar" texture described by ESTEBAN (1974).

Interpretation

The tubular structures that cross-cut the dolomitic host rocks are pseudomorphs after root clannelways. KLAPPA (1980) used the term "rhizoliths" to describe analogous organosedimentary structures produced by roots, including "accumulation and/or cementation around, cementation within or replacement of higher plant roots by mineral matter" (p. 615). The observed tubular voids correspond to the "root moulds" while the needle-fibre calcite coatings to the "root tubules" (sensu KLAPPA, 1980). According to the same terminology the carbonate fillings of the tubular voids (glaebular micrite and/or blocky spar) correspond to the "root casts". The observation of dichotomus branching and decrease in bifurcations diameters further justify the approach that the tubular voids reflect the position of previously root paths. Such voids are not produced by burrowing organisms, because burrows usually have uniform diameters and their inner-most canal is composed of fecal pellets. Analogous tubular voids have been recorded by many authors from weathered zones of caliche crusts (JAMES, 1972; WARD, 1975) and represent a common and characteristic feature in Quaternary calcretes from several coastal regions of the Western Mediterranean (KLAPPA, 1978 b; 1979). Similar rhizolitic textures have been identified in the post-Pliocene solution-collapse breccia, in Eastern Crete (POMONI-PAPAIOANNOU and DORNSIEPEN, 1987). Concerning the origin of the needle-fibre calcite coatings, that are responsible for the preservation of roots morphology after roots have been completely decayed, two controversial aspects have been expressed. The first supports a biogenic influence (HARRISON, 1977; WARD, 1970; CHAFETZ, WILKINSON and LOVE, 1985; WRIGHT, 1984, 1986), while the

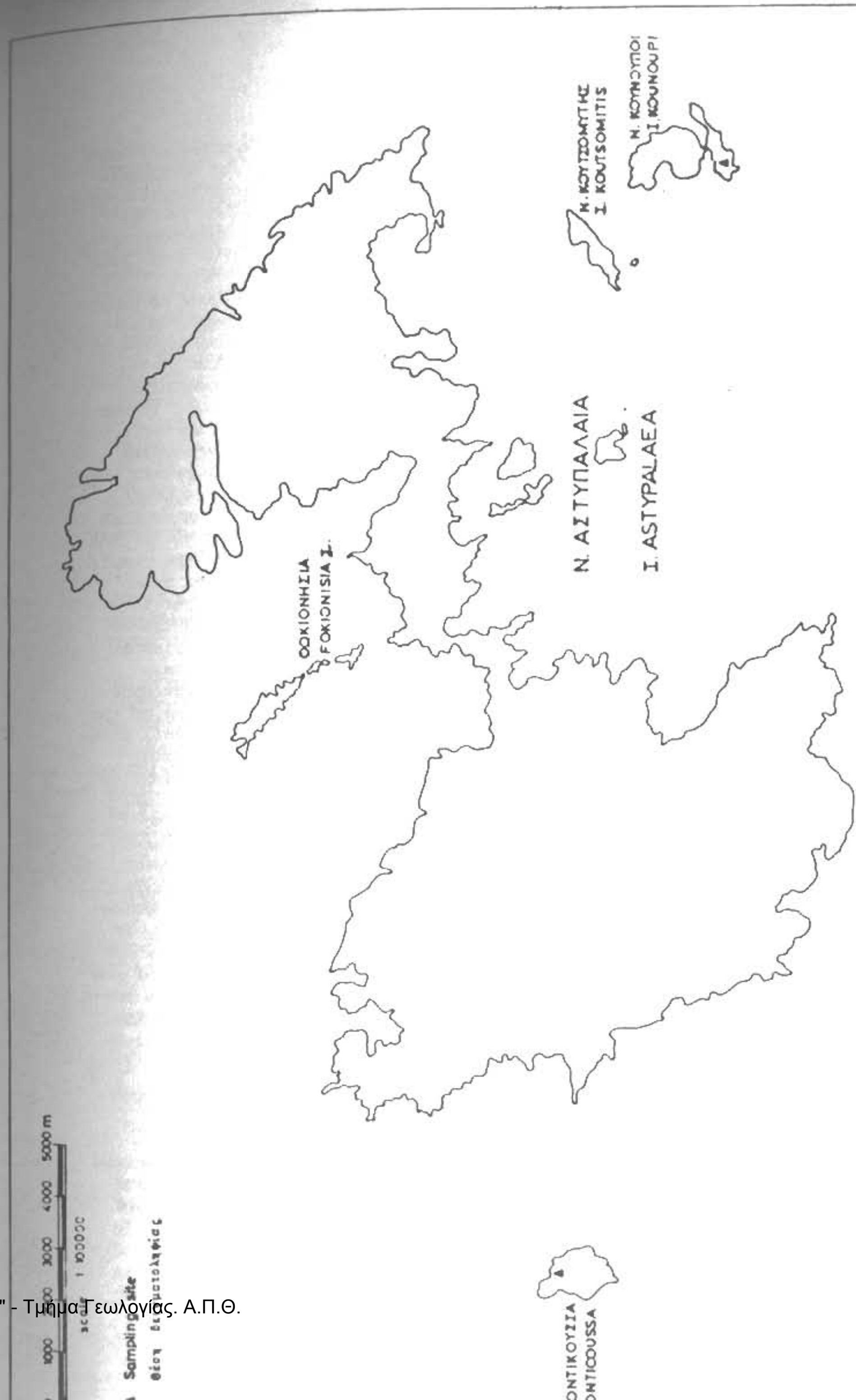


Fig. 1 Astypalaea island and the adjacent islets.
Σχ. Νήσος Αστυπάλαια με τις νησίδες της

second regards it as having been formed inorganically during extremely high degrees of supersaturation caused by rapid degassing of CO_2 and or evaporation (JAMES, 1972; SOLOMON and WALKDEN, 1985). Our observations justify the first approach considering that roots themselves are responsible for the formation of the needle-fibre sheaths. The process could probably correspond to an impregnation of the plant root either during decay or even while the roots were still alive, as KLAPPA (1980) stated.

The crusts which overlie the dolomite host rocks correspond to pedogenic caliche crusts, produced by accumulation of calcium carbonate material. The responsible for the spherulitic crust formation mechanism, proved to be complicated. The blunt terminations of most of the crystals in the observed spherulites seem to suggest neomorphism after former aragonite crystals (LOUCKS and FOLK, 1976; FOLK and ASSERETO, 1976). However, it must be noted that the primary length-slow calcite cement presents a morphology similar to this resulted by neomorphism of a bundle of aragonite needles (from CHAFETZ and BUTLER, 1980 p. 506). The observed spherulitic crusts are similar to the so called "Microcodium-Like Structures" observed by CHAFETZ and BUTLER (1980) in the Recent caliche sediments of Central Texas, due to the strong resemblance with the Microcodium structures described by ESTEBAN (1973). According to KLAPPA'S (1978 a) definition Microcodium is the result of "calchification of mycorrhizae,a symbiotic association between fungi and cortical cells of roots" (p. 518). Our observations suggest that formation of the spherulites through a bacterially controlled neomorphism of the radiating calcite prisms of Microcodium or Microcodium-like bodies as CHAFETZ and BUTLER (1980) stated, could be the responsible mechanism.

The glaebular matrix that occupies the interspace between the spherulitic crusts is of pedogenic origin and resulted by transformation of the host rocks. BREWER (1964) defined glaebules as "prolate to equant soil unit of different fabric from, or having a distinct boundary with, enclosing soil material" (p. 355), whereas according to BRAITHWAITE (1983) glaebules result by an in-situ solution and reprecipitation of carbonate material.

The origin of the alveolar texture is regarded to be related to rhizoconcretionary fabrics (encrustations of roots). Comparable textures have been illustrated and described by many authors in fossil and recent calcretes and are considered exclusive to such formations (ESTEBAN, 1974; BRAITHWAITE, 1975; ADAMS, 1980; PERYT & RUP, 1987). A detailed description of alveolar texture was given by ESTEBAN and KLAPPA (1983) considering it "consisting basically of a number of cylindrical to irregular pores, which may or may not be filled with calcite cement, separated by a network of anastomosing micritic walls" (p. 26). The needle-fibre calcite sheaths is considered to be evidence of fungal activity around roots. WRIGHT (1986) introduced the term alveolar-septal texture to distinguish it from the alveolar texture in which septae are absent.

Isl. Pontikoussa (Fig. 1)

It is situated on the western side of Astypalea and is characterized by low altitude of the order of 5 m a.s.l. The host rocks are coastal porous grainstones that are widely extended especially in the northern part of the island. Their thickness reach the 4-5 m (Schem. Sect. No 2).

Microscopical Description

Clean-washed and highly porous lithoclastic mud-free skeletal grainstones were observed. The skeletal grains are mainly fragments of corallinacean algae and echinoderms with lesser amount of forams, molluscs and brachiopods while the lithoclasts are mainly serpentinites as well as metamorphic rocks of the subenvironment (chlorite schists, quartzites, e.t.c.). Large undifferentiated peloids have been observed in places (PL. II, Fig. 2).

Most of the above components are surrounded by reddish-brownish concentric irregular micritic coatings consisting of bundles of tangentially oriented calcite needles. The thickness of the coatings varies between the different grains as well as in the grain itself, but generally they are very thin. Grain coatings show characteristic irregular protuberances. In places a bridging-like fabric consisting of small peloids has been developed, giving the impression of binding grains to each other (PL. II, Fig. 2,3). A thin rim of fresh-water cement (dog-teeth or blady calcite) has been precipitated on the grains, while the remaining space has been partially occluded by blocky calcite spar. Pendant and meniscus cement have developed on some grains. However most of the primary intergranular porosity is still preserved. In places botryoidal crusts have been developed.

Interpretation

The studied grainstone deposits were deposited in a well-agitated subtidal environment. As far as the environment of the different cement types is concerned, precipitation in the realm of meteoric environment is suggested. Specific characteristic of the vadose zone is the pendant (dripstone or gravitational) and the menicus cement.

Predominant diagenetic feature is the development of grain coatings which have grown subaerially, involved in the calichification process. The coatings observed have no relation with the micrite coatings described by BATHURST (1964), which develop during marine diagenesis. The boundaries between grains and coatings are usually fuzzy and indistinct, feature characteristic for caliche coatings implying progressive alteration. (BRAITHWAITE, 1983). Similar caliche coatings (the so-called calcans of calcitans in the soil terminology) are common in Quaternary calcretes supposed to have a microbial origin (JAMES, 1972; HARRISON, 1977; KNOX, 1977;WRIGHT, 1986). Our observations favour a root biomineralization mechanism through an accretional and centrifugal mechanism, analogous to that described by CALVET and JULIA (1983).

Isl. Lagoubardos (Fig. 2)

It is situated in the Northern-Western part of Antikithira and is composed of Neogene boundstones and grainstones. Its altitude is about 40 m a.s.l. The crusts form lenses in the Neogene sediments (Schem. Sect. No 4).

Microscopical Description

The host rocks are dolomitized boundstones and packstones-floatstones (PL. III, Fig. 1). The boundstones are composed of in-situ grown colonies of corallinacean algae, dasycladaceans and bryozoans. The interskeletal voids are occupied by a mud-supported packstone-floatstone consisting of skeletal grains, mainly echinoderms, forams, gastropods and molluscs. Geopetal structures are common (PL. III, Fig. 1). The packstones-floatstones are mainly composed of molluscs, gastropods, forams and echinoderms and are characterized by high porosity, due to shell dissolution. A thin dog-teeth rim cement surrounds the produced molds. In the upper part of some voids

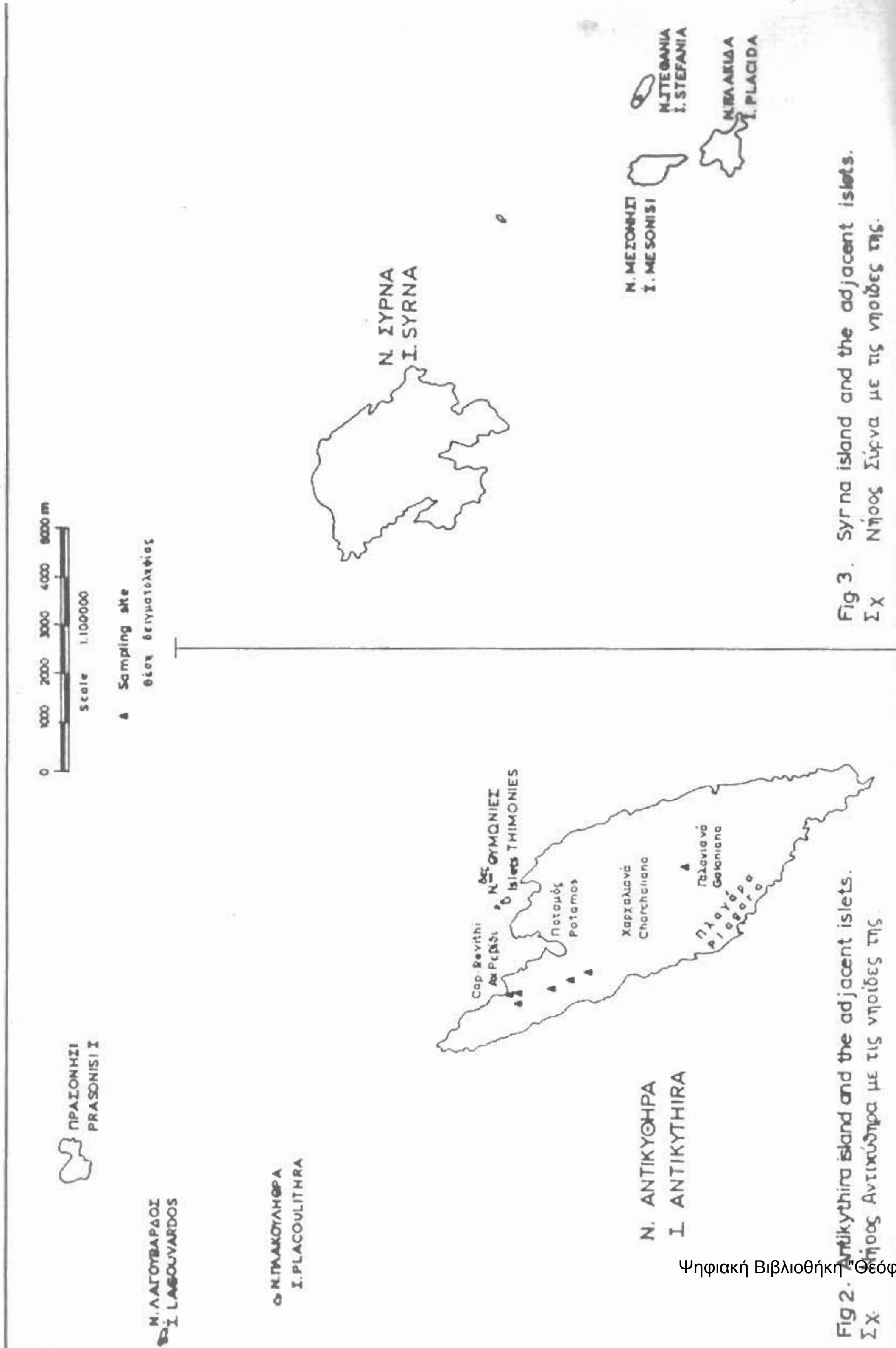


Fig 2. Antikythira island and the adjacent islets.
Σχ. Νήσος Αντικύθηρα με τις νησίδες της.

Fig 3. Syrna island and the adjacent islets.
Σχ. Νήσος Σύρνα με τις νησίδες της.

pendant cement has precipitated. The surrounding matrix is composed of homogeneous micrite with abundant small-sized subspherical to irregular voids internally surrounded by a thin yellowish argillaceous rim.

The overlying crusts display characteristic branched tubular structures similar with those described in the caliche crusts of Kounoupi island (PL. III, Fig. 2). Concentrical coatings of needle-fibre calcite sheaths have precipitated on the tubule walls and usually cross-cut the cylindrical pores, resulting in a texture similar with the so-called alveolar (ADAMS, 1980; POMONI-PAPAIOANNOU & DORNSIEPEN, 1987), or alveolar-septal (WRIGHT, 1986; PERYT & RUP, 1987). In situ-grown spherulitic-botryoidal crusts associate the tubular cavities, being composed of closely connected and laterally extended spherical to ellipsoidal grains.

Interpretation

The accumulation of mechanically introduced mud in the interskeletal cavities of the boundstones is indicative of subaerial diagenesis. The high-porosity of the packstones-floatstones is of interskeletal type, produced by dissolution of aragonite or high-Mg calcite shells by freshwaters. Cement types (dog-teeth, pendant) support precipitation in the meteoric-vadose realm.

The tubular structures are interpreted to represent organosedimentary structures produced by roots (rhizoliths, sensu KLAPPA, 1980), while the formation of needle-fibre sheaths around the tubule walls are considered to be biogenically controlled, either during decay or during root's life.

Concerning the origin of the Microcodium-like spherulitic structures we favor the same mechanism as for the crusts observed in Kounoupi isl., involving a bacterially controlled neomorphism of Microcodium or Microcodium-like bodies.

Isl. Stefania (Fig. 3)

It is situated at the southeastern part of the island Syrna and shows an altitude of about 20 m a.s.l. The crusts overlie medium to thick-bedded strongly recrystallized Jurassic dolomitic limestones and dolomites. They show a broad extension covering 2/3 of the whole island and their thickness ranges from 0-5 m (Schem. Sect. No 3).

Microscopical Description

The host dolomites are overlain by yellowish-brownish lime crusts characterized by glaebular structure. Laterally extended spherulitic-botryoidal crusts composed of closely connected spherical to ellipsoidal grains, similar to those of the Kounoupi isl., interrupt the glaebular matrix (PL. III, Fig. 3). Round to elliptical voids surrounded by poorly developed coatings are observed in places.

Interpretation

The glaebules observed are of pedogenic origin, either formed by the alteration of skeletal grains and/or other components of the substrate through calichification, as JAMES (1972) stated, or through a solution-reprecipitation mechanism, analogous to that proposed by BRAITHWAITE (1983).

The formation of the spherulitic-botryoidal crusts as previously has stated is considered to result through an organically controlled mechanism analogous to that proposed by CHAFETZ & BUTLER (1980).

Isl. Antikythira. (NW coast, Revithi Cap) (Fig. 2).

Crusts cross-cut the coastal grainstones as well as the host boundstone formations (Schem. Sect. No 5). Underneath occur the Paleocene-Eocene greyish to black, thick-bedded, nummulite-bearing, dolomitized limestones of Tripolis zone.

Microscopical Observation

The observed crusts consist of a yellowish-brownish carbonate material, characterized by the presence of rounded-irregular cavities, as well as by branched tubular cavities (PL. IV, Fig. 1,2). Relics of corallinacean algae and chert lithoclasts occur locally. The tubular voids are surrounded by tangential needle-fibre calcite sheaths and have been partially or wholly occluded by blocky spar (PL. IV, Fig. 2). In places the sheaths form a characteristic net, separating irregular voids and giving birth to a texture similar to the alveolar texture (PL. IV, Fig. 3). Terrigenous quartz have been observed in places.

Interpretation

The above facies corresponds to a well-developed rhizoconcretionary caliche. The interpenetrating system of tubular voids correspond to preexisting root paths, that have completely modified and destroyed the original structures and through their calcification give birth to the observed structures. The accumulation of carbonate material around the plant root is effectuated through pedogenic mechanisms, finally resulting in rhizoconcretionary caliche formation (PL. IV, Fig. 4). The tubular voids correspond to root moulds, while the coating needle-fibre calcite sheaths to root tubules, sensu KLAPPA (1980). Concerning the origin of the alveolar-like or alveolar septal-like texture observed, as has been stated before it is considered to represent a rhizoconcretionary fabric. The interpenetration of plant roots and the intense biological weathering produced in-situ brecciation.

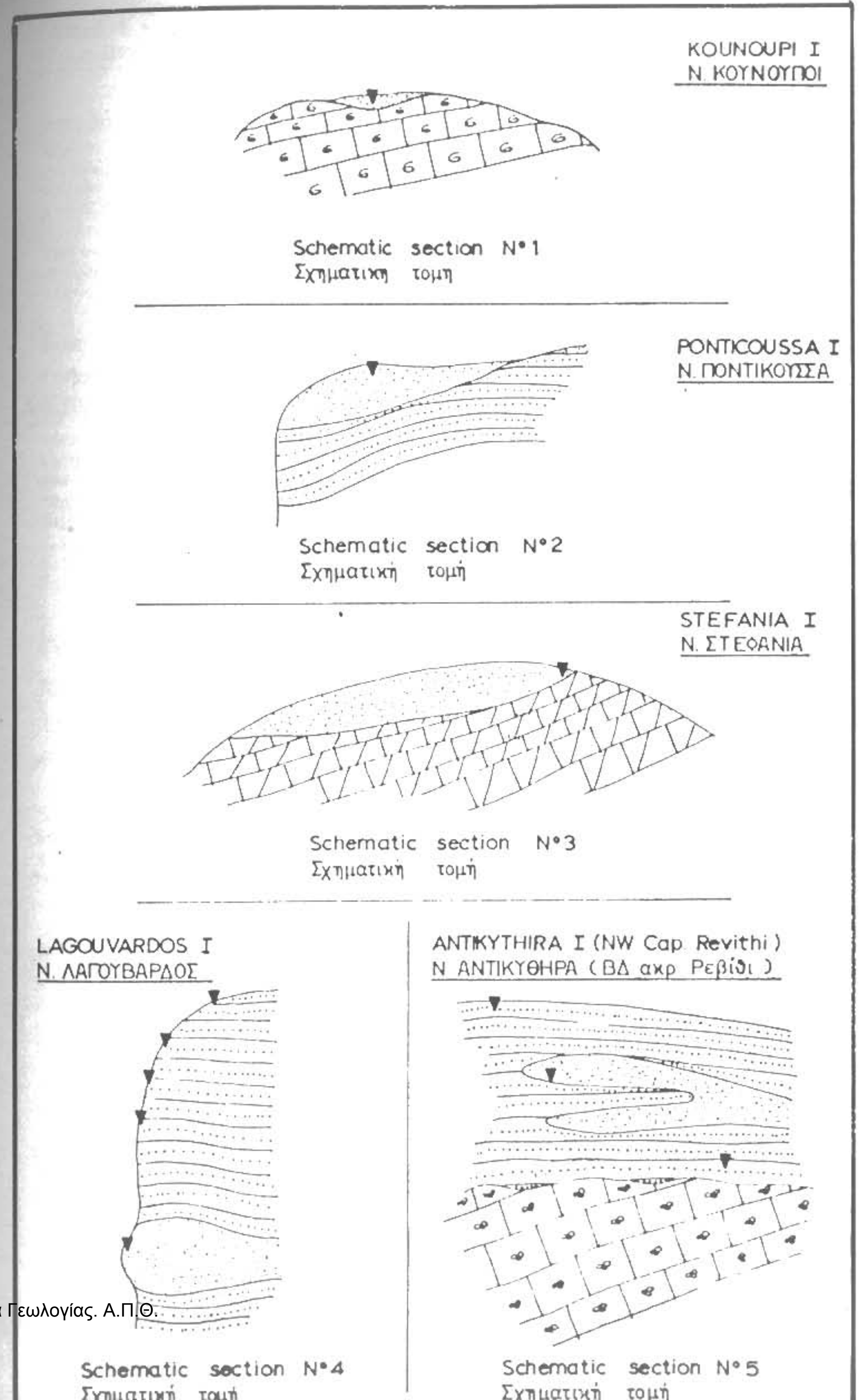
Isl. Antikythira (Western of village Potami). (Fig. 2).

Crusts have been developed along the contact with a grainstone coastal formation similar to the Revithi cap, and to the Pontikoussa formations (Schem. Sect. No 6).

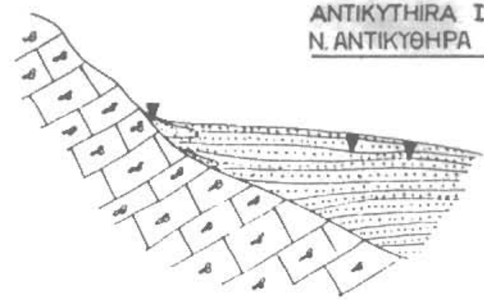
Microscopical Description

Mud-free, grain-supported lithoclastic skeletal grainstones are observed (PL. V, Fig. 1). The marine bioclasts are mainly corallinacean algae, echinoderms,bryozoans, forams and in smaller amount brachiopods and molluscs. The lithoclasts are mainly radiolarian cherts and quartzites (PL. V, Fig. 1) Terrigenous quartz grains are common. This facies is characterized by high inter-as well as intra-skeletal porosity. All the grains show well-developed grain coatings composed of thin concentric irregular laminations consisting of needle-fibre calcite sheaths. The grain coatings display irregular protuberances and dissimilar thickness. A thin rim of dog-teeth cement surrounds the already coated grains while the rest part either remains open or has been filled by blocky spar, giving birth to grainstone fabrics. A bridging-like fabric consisting of small peloids bind the coated grains (PL. V, Fig. 1).

Mud-free pisolitic grainstones deposits have also developed (PL. V, Fig. 2). The pisoids (diameters from 200 µm to 35 mm) yield a nucleus of

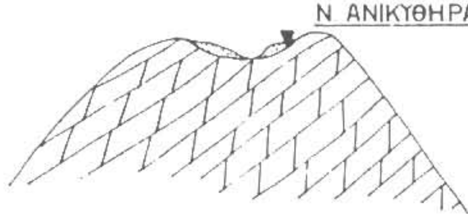


ANTIKYTHIRA I. (N of Potami)
N. ANTIKYΘHPA (B του Ποταμού)



Schematic section N° 6
Σχηματική τομή

ANTIKYTHIRA I (E of Galaniana)
N ANIKYΘHPA (A των Γαλανιανών)



Schematic section N° 7
Σχηματική τομή

LEGEND		ΥΠΟΜΝΗΜΑ
NEOGENE – QUATERNARY		ΝΕΟΓΕΝΕΣ – ΤΕΤΑΡΤΟΓΕΝΕΣ
Caliche		Κρούστα
Calcarenite		Αοβεσταρενίτης
TRIPOLIS ZONE		ΖΩΝΗ ΤΡΙΠΟΛΗΣ
UPPER EOCENE – OLIGOCENE (?)		ΑΝΩΤΕΡΟ ΗΩΚΑΙΝΟ ΟΛΙΓΟΚΑΙΝΟ (?)
Psammite – conglomerated flysch		Ολύσχης ψαμμιτο-κροκαλοπαγής
PALEOCENE – MIDDLE EOCENE		ΠΑΛΑΙΟΚΑΙΝΟ – ΜΕΣΟ ΗΩΚΑΙΝΟ
Dark grey, thick-bedded, nummulitic limestones		Σκοτεινότεφροι, παχυστρωματώδεις, νουμμουλιτοφόροι ασβεστόλιθοι.
UPPER CRETACEOUS		ΑΝΩΤΕΡΟ ΚΡΗΤΙΔΙΚΟ
Dolomites		Δολομίτες.
Black, thick-bedded to massive, rudist-bearing limestones		Μαύροι, παχυστρωματώδεις έως άστρωτοι, ρουδιστοφόροι ασβεστόλιθοι.
LYCIAN NAPPES		ΛΥΚΙΑΚΑ ΚΑΛΛΥΜΑΤΑ
JURASSIC		ΙΟΥΡΑΣΙΚΟ
Dolomitized limestones		Δολομιτιωμένοι ασβεστόλιθοι
Sampling site	▼	Θέση δειγματοληψίας

variable nature and shape (skeletal grains, peloids, lithoclasts, quartz grains) (PL. V, Fig. 2). The envelopes have uniform thickness, which is usually smaller than the nucleus diameter. The elliptical-subrounded shape of the pisoids is due to a tendency of coating thinning at the prominent nucleus edges and corners (PL. V, Fig. 2). The pisoid coatings are consisting of tangentially orientated whisker calcite crystals. Blocky calcite spar is the cementing material. In places, structures consisting of concentrically arranged needle-fibre sheath alternations have been observed as well as an alveolar-septal texture (PL. V, Fig. 3).

Interpretation

The development of coatings around the skeletal and the lithoclastic grains is the principal diagenetic feature. The formation of the coatings is involved in the calichification process, during subaerial exposure of sediments. Needle-fibre calcite sheaths around grains are supposed to result through a root biomineralization mechanism. The pisoid grainstones are formed by progressive calichification. Pisoids were probably formed through centrifugal accretion mechanism analogous to that proposed by CALVET & JULIA (1983). The observed pisoids are of pedogenic origin and are not related to vadose pisolites which are formed in hypersaline environments. Pisolitic caliche formations have been also observed in Eastern Crete (POMONI-PAPAIOANNOU & DORNSIEPEN, 1987).

Isl. Antikythira-Central part (East of Galaniana, Fig. 2).

Remnants of crusts have been observed up to an altitude of about 300 m a.s.l., on black Paleocene-Eocene dolomitized limestones (Schem. Sect. No 7).

Microscopical Description

Facies observed are analogous to those in the NW coast. A yellowish-brownish fairly opaque matrix enriched in Fe-oxides is observed, interrupted by tubular cavities as well as by a system of interconnecting irregular cavities (PL. V, Fig. 4). Relic skeletal grains (brachiopods, echinoderms, corallinacean algae, molluscs) are still preserved.

Interpretation

The observed facies correspond to rhizoconcretionary caliche. Massive, as well as glaebular caliche types were also observed. The rocks show several rhizoconcretionary fabrics including root moulds, root tubules, root casts (sensu KLAPPA, 1980), as well as alveolar-septal textures (WRIGHT, 1986).

CONCLUSIONS

The sedimentological study of the uppermost crusts observed in several islands of Southern-Eastern Aegean, as well as of Southern Ionian Sea revealed that they represent pedologic formations resulted by calichification of the substrates during a prolonged subaerial exposure. The amount of $CaCO_3$ necessary for calichification is considered to be mostly provided by weathering of calcareous host rocks. Several caliche microfacies have been recognized including glaebular-massive, pisolitic, laminar as well as rhizoconcretionary types. Plant roots are involved in most of the diagenetic alteration processes producing characteristic rhizolitic structures (root moulds, root tubules, root casts, alveolar textures e.t.c.). Roots are also responsible, through calichification, for the formation of coatings around the skeletal and lithoclastic grains of coastal calcarenitic deposits, giving birth by prolonged exposure to caliche pisoids. The plant roots resulted in intense biological weathering of the substrates, which suffer secondary micritization and in-situ brecciation.

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PLATE I

Fig. 1. Sharp contact between the host dolomitic rocks (base) and the overlain caliche crusts. Starting of spherulitic crusts on the upper most part. ' stratification. Isl. Kounoupi, // Nicols, 30 X

Απότομη επαφή μεταξύ των μητρικών δολομιτικών πετρωμάτων (στη βάση) και των υπερκείμενων φλοιών caliche. Έναρξη δημιουργίας σφαιρολιθικών επιφλοιώσεων στο πλέον ανώτερο τμήμα. Τομή ' στρώση. Νησ. Κουνούποι, // Nicols, 30 X

Fig. 2. Rhizoconcretionary tubular structures cross-cutting the host dolopseudosparite. The tubules are branched and show decreased distally diameters. Sect. ' stratification. Isl. Kounoupi, // Nicols, 30 X

Ριζογενείς σωληνοειδείς δομές, που διακόπτουν τα μητρικά δολοψευδοσπαριτικά πετρώματα. Παρατηρείστε το σύστημα διακλάδωσης των δομών αυτών καθώς και την τάση ελάττωσης της διαμέτρου των σωλήνων πλευρικά. Τομή ' στρώση. Νησ. Κουνούποι, // Nicols, 30 X

Fig. 3. Spherulitic crusts exhibiting a botryoidal way of growth, composed of closely connected spherical to ellipsoidal bodies, consisted of bundles of radially arranged calcite fibres. Note the relic concentric-zoned structure. Sect. ' stratification. Isl. Kounoupi, // Nicols, 30 X

Σφαιρολιθικές επιφλοιώσεις με βοτρυοειδή ανάπτυξη, συνιστάμενες από στενά συνδεδεμένα σφαιρικά-ελλειψοειδή σωματίδια, αποτελούμενα από δεσμίδες ακτινωτά διατεταγμένων ασβεστιτικών ινών. Σημειώστε την υπολειμματική συγκεντρική-ζωνώδη δομή. Τομή ' στρώση. Νησ. Κουνούποι, // Nicols, 30 X

Fig. 4. Spherulitic crusts between a glaebular caliche matrix, composed of closely connected spherical to ellipsoidal bodies with radial internal structure. Sect.' stratification. Isl. Kounoupi, Nicols, 30 X

Σφαιρολιθικές επιφλοιώσεις παρεμβαλλόμενες μεταξύ μιας μάζας caliche πελμικριτικού ιστού, αποτελούμενες από στενά συνδεδεμένα σφαιρικά-ελλειψοειδή σωματίδια με ακτινωτή εσωτερική δομή. Τομή ' στρώση. Νησ. Κουνούποι, Nicols, 30 X

PLATE II

Fig. 1. Alveolar-septal like texture, consisted of ellipsoidal to subrounded voids, coated by needle-fibre calcite sheaths. The illustrated texture is considered to result by a root biominelization process. Sect. ' stratification. Isl. Kounoupi, Nicols, 30 X

Δομή τύπου alveolar-septal, αποτελούμενη από ελλειψοειδείς-υποσφαιρικές οπές, που περιβάλλονται από βελονοειδείς-ινώδεις ασβεστιτικούς κρυστάλλους. Η εικονιζόμενη δομή θεωρείται ότι προκύπτει μέσου ενός μηχανισμού ελεγχόμενου άμεσα από την παρουσία φυτικών ριζών (root biomineralization). Τομή ' στρώση. Νησ. Κουνούποι, // Nicols, 30 X

Fig. 2. Clean-washed mud-free lithoclastic skeletal grainstones. The skeletal grains are mainly fragments of corallinacean algae and echinoderms with lesser amounts of molluscs and other bioclasts. Note the thin pedogenic coatings around the grains. Isl. Pontikoussa, // Nicols, 30 X

Fig. 2. Clean-washed mud-free lithoclastic skeletal grainstones. The skeletal grains are mainly fragments of corallinacean algae and echinoderms with lesser amounts of molluscs and other bioklasts. Note the thin pedogenic coatings around the grains. Isl. Pontikoussa, // Nicols, 30 X

Λιθοκλαστικοί σκελετικοί grainstones, χωρίς ιλύ. Οι σκελετικοί κόκκοι αντιπροσωπεύονται κύρια από θραύσματα κοραλλιογενών φυκών και εχινοδέρμων και σε μικρότερο ποσοστό από μαλάκια και άλλους βιοκλάστες. Παρατηρείστε τα λεπτά πεδογενετικά καλύμματα γύρω από τους κόκκους. Νησ. Ποντικούσα, // Nicols, 30 X

Fig. 3. Same. The between the grains micritic matrix is of pedogenic origin. Note the characteristic coating protuberances around the coarse grain in the centre. Isl. Pontikoussa, // Nicols, 30 X

Ομοίως. Η μεταξύ των κόκκων μικριτική ιλύς είναι πεδογενετικής προέλευσης. Παρατηρείστε τα χαρακτηριστικά εξογκώματα του καλύμματος γύρω από τον αδρομεγέθη κόκκο στο κέντρο. Νησ. Ποντικούσα, // Nicols, 47, 5 X

P L A T E III

Fig. 1. Boundstones composed of in-situ grown colonies of corallinacean algae and bryozoans. Note the geopetal structures. Sect. ' stratification. Isl. Lagoubardos, // Nicols, 30 X

Boundstones αποτελούμενοι από in-situ αναπτυσσόμενες αποικίες κοραλλιογενών φυκών και βρυοζώων. Παρατηρείστε τις γεωπεταλικές δομές. Τομή ' στρώση. Νησ. Λαγούβαρδος, // Nicols, 30 X

Fig. 2. Rhizoconcretionary tubular structures cross-cutting the overlying caliche crusts. Sect. ' stratification. Isl. Lagoubardos, // Nicols, 30 X

Ριζογενείς σωληνοειδείς δομές που διακόπτουν τους υπερκείμενους φλοιούς caliche. Τομή ' στρώση. Νησ. Λαγούβαρδος, // Nicols, 30 X

Fig. 3. Sharp contact between the host dolomitic rocks and the overlying glaebular caliche. Note the botryoidal-spherulitic crust at the upper part, exhibiting a characteristic concentric-zoned relic structure. Sect. ' stratification. Isl. Stefania, // Nicols, 30 X

Απότομη επαφή μεταξύ των μητρικών δολομιτικών πετρωμάτων και της υπερκείμενης φάσης caliche, πελμικριτικού ιστού. Παρατηρείστε στο ανώτερο τμήμα τις βοτρυοειδείς-σφαιρολιθικές επιφλοιώσεις που χαρακτηρίζονται από μία συγκεντρική-ζωνώδη υπολειμματική δομή. Τομή ' στρώση. Νησ. Στεφανία, // Nicols, 30 X

P L A T E IV

Fig. 1. Rhizolitic structures cross cutting a micritic matrix of pedogenic origin. Note the branching and decreased distally tubules diameters as well as the micritic coatings around the root molds. Sect. ' stratification. NW coast of Antikithira (Revithi cap), // Nicols, 30 X

Ριζολιθικές δομές που διακόπτουν μία μικριτική μάζα πεδογενετικής προέλευσης. Παρατηρείστε το σύστημα διακλάδωσης και την τάση ελάττωσης των διαμέτρων των σωλήνων καθώς και τα μικριτικά καλύμματα γύρω από τα ίχνη των ριζών. Τομή ' στρώση. ΒΔ ακτή Αντικυθήρων (Ακρωτήρι Ρεβίθι), Nicols, 30 X

Fig. 2. Laterally extended tubular cavities corresponding to root pathways (root moulds). Sect. ' stratification. NW coast of Antikithira (Revithi cap), // Nicols, 47,5

Πλευρικά εκτεινόμενες κοιλότητες σωληνοειδούς τύπου που αντιστοιχούν σε διόδους ριζών. Τομή ' στρώση. ΒΔ ακτή Αντικυθήρων (Ακρωτήρι Ρεβίθι), // Nicols, 47,5 X

Fig. 3. Alveolar-septal texture. Note the way micritic sheaths separate irregular voids in a laterally extended root tubule. Sect. ' stratification. NW coast of Antikithira (Revithi cap), // Nicols, 47,5 X

Δομή τύπου alveolar-septal. Σημειώστε τον τρόπο με τον οποίο τα μικριτικά καλύμματα διαχωρίζουν ανώμαλους πόρους σε μία πλευρικά εκτινόμενη ριζολιθική δομή. Τομή ' στρώση. ΒΔ ακτή των Αντικυθήρων (Ακρωτήρι Ρεβίθι), // Nicols, 47,5 X

Fig. 4. Cross-section of a rhizolitic structure. The accumulation of carbonate material inside and around the plant root is effectuated through calichification. Sect. ' stratification. NW coast of Antikithira (Revithi cap), // Nicols, 30 X

Εγκάρσια τομή μιας ριζολιθικής δομής. Η απόθεση ανθρακικού υλικού μέσα και γύρω από την ρίζα επιτυγχάνεται μέσω πεδογενετικών μηχανισμών (calichification). Τομή ' στρώση. ΒΔ ακτή των Αντικυθήρων (Ακρωτήρι Ρεβίθι), // Nicols, 30 X

P L A T E V

Fig. 1. Lithoclastic skeletal grainstones. Grains show well developed irregular needle-fibre grain-coatings, supposed to be controlled by a root biomineralization process. Note the grain-coatings protuberances, as well as the accumulation of small peloids between the coated (bridging-like fabric). Isl. Antikithira (western of village Potami), // Nicols, 47,5 X

Λιθοκλαστικοί σκελετικοί grainstones. Οι κόκκοι περιβάλλονται από καλά ανεπτυγμένα, ανώμαλα καλύμματα, βελονοειδών-ινωδών ασβεστιτικών κρυστάλλων, η απόθεση των οποίων θεωρείται ότι ελέγχεται από την παρουσία ριζών. Παρατηρείστε τις εξογκώσεις των καλυμμάτων των κόκκων, καθώς και την συγκέντρωση μικρών πελοειδών μεταξύ επιφλοιωμένων κόκκων (γεφυροειδής δομή). Νησ. Αντικύθηρα (Δυτικά των Ποταμών), Nicols, 47,5

Fig. 2. Pisolitic grainstones, consisted of pisoids of variable size. The nuclei differ in nature, size and shape. Note the tendency of coatings to thin at the prominent adges and corners, resulting to ellipsoidal pisoids. A circum-granular cracking is observed in the coarse pisoid at the right part. Isl. Antikithira (western of village Potami), Nicols, 120 X

Πισολιθικοί grainstones, αποτελούμενοι από πισοειδή διαφόρων μεγεθών. Οι πυρήνες διαφέρουν στην φύση, μέγεθος και σχήμα. Σημειώστε την τάση των καλυμμάτων προς λέπτυνση στις προεξέχουσες ακμές και γωνίες, με αποτέλεσμα τη δημιουργία ελλειψοειδών πισοειδών. Μία λεπτή συγκεντρική ρωγμάτωση στο αδρομερές πισοειδές, στο δεξιό τμήμα. Νησ. Αντικύθηρα (Δυτικά των Ποταμών), Nicols, 120 X

Fig. 3. Rhizoconcretionary caliche. In the picture a cross-section of a rhizolite structure is illustrated. An alveolar-septal like texture tends to develop. Isl. Antikithira (western of village Potami), // Nicols, 30 X

Ριζογενής caliche. Στην φωτογραφία απεικονίζεται μία εγκάρσια τομή ριζολιθικής δομής. Δομή τύπου alveolar-septal τείνει να αναπτυχθεί. Νησ. Αντικύθηρα (Δυτικά των Ποταμών), // Nicols, 30 X

Fig. 4. Rhizoconcretionary-massive caliche consisted of a pedogenic micritic matrix. Small subrounded cavities have been observed in places, regarded to correspond to root moulds. Isl. Antikithira (east of Galaniana), // Nicols, 30 X

Ριζογενής-συμπαγής caliche αποτελούμενη από πεδογενετική μικριτική μάζα. Κατά θέσεις παρατηρούνται μικρές υποσφαιρικές κοιλότητες, που θεωρούνται ότι αντιστοιχούν σε αποτυπώματα ριζών. Νησ. Αντικύθηρα (Ανατολικά των Γκαλανιανών), // Nicols, 30 X

PLATE I — ΠΙΝΑΚΑΣ I

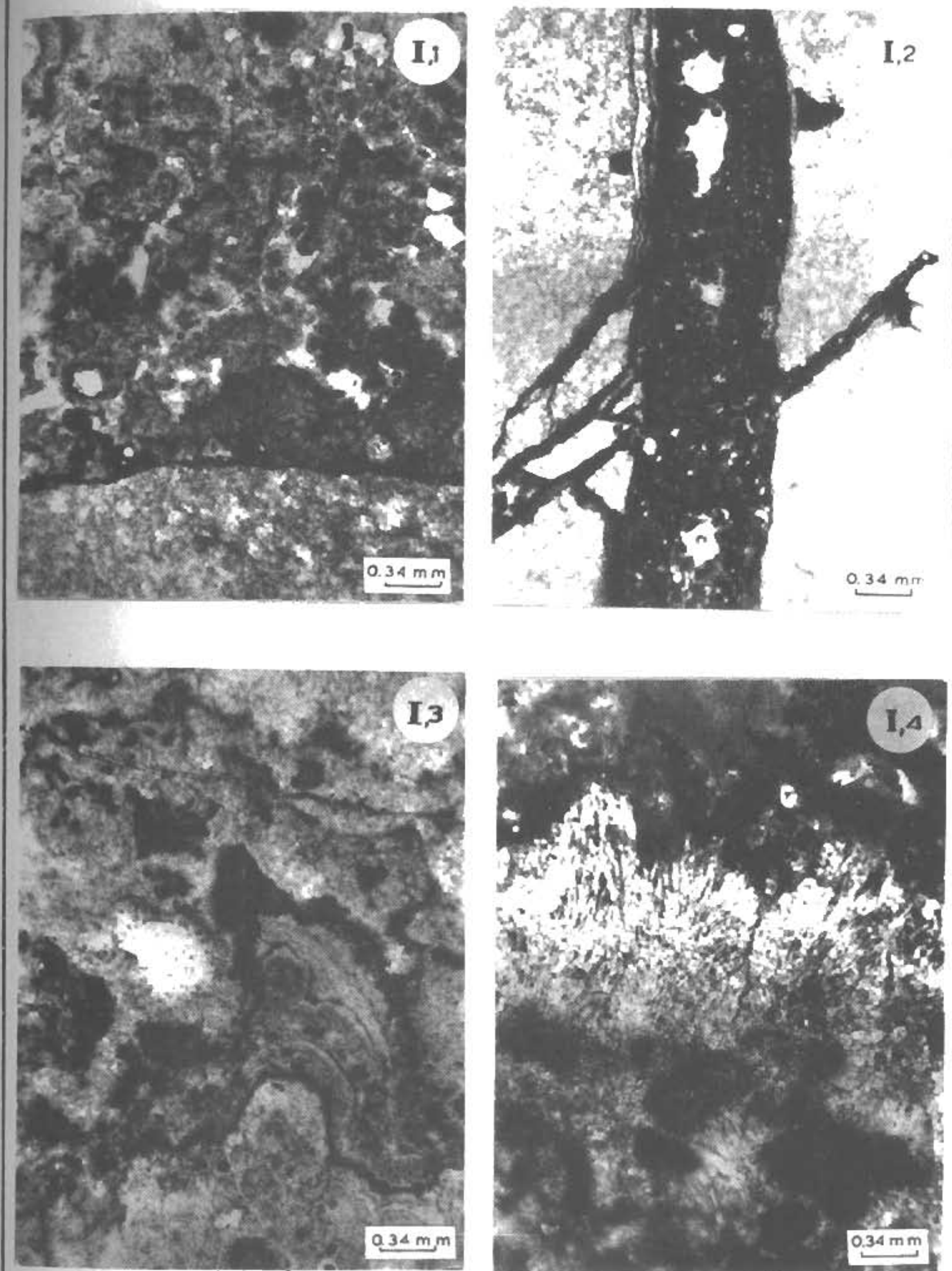

PLATE II - ΠΙΝΑΚΑΣ II

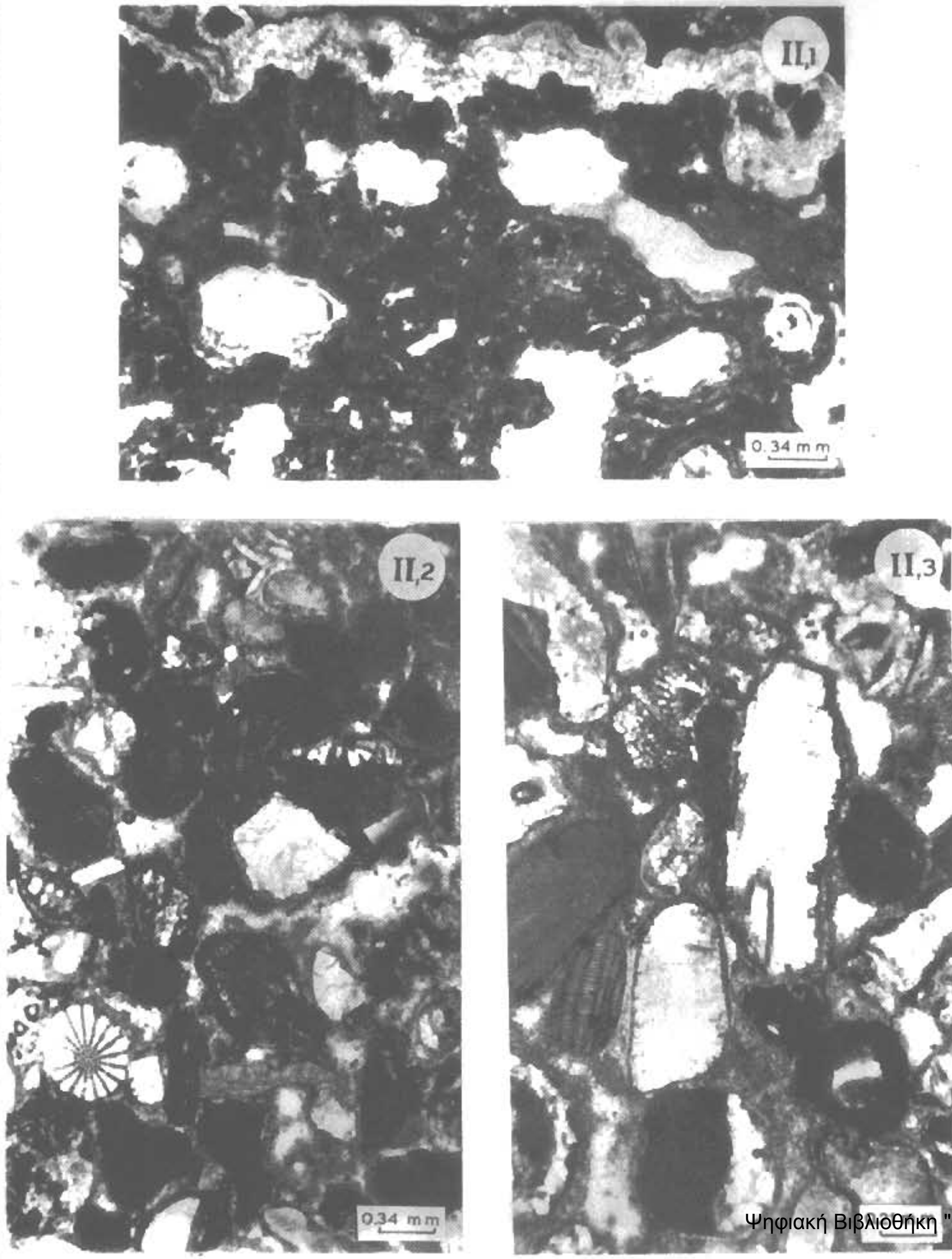

PLATE III - ΠΙΝΑΚΑΣ III

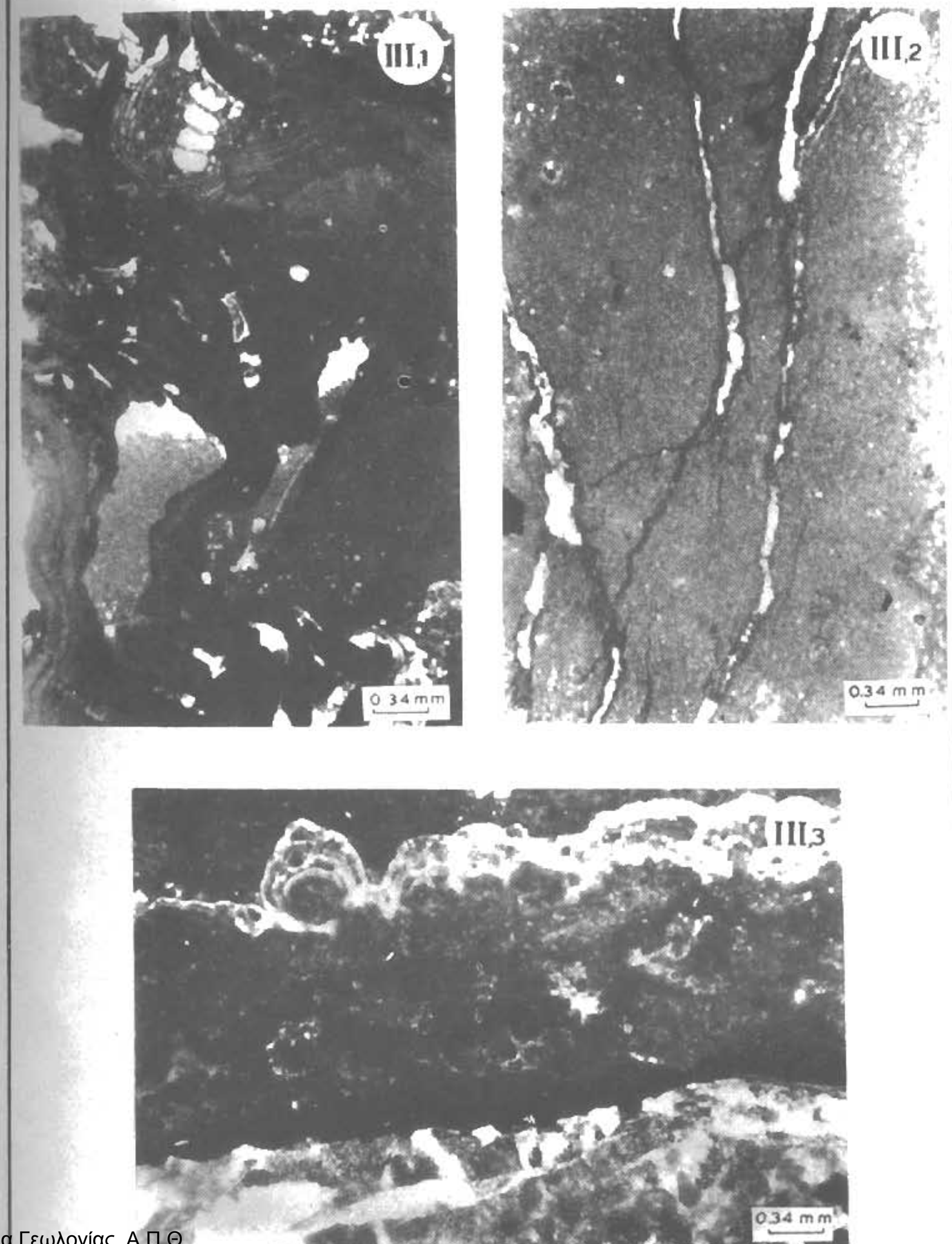

PLATE IV – ΠΙΝΑΚΑΣ IV

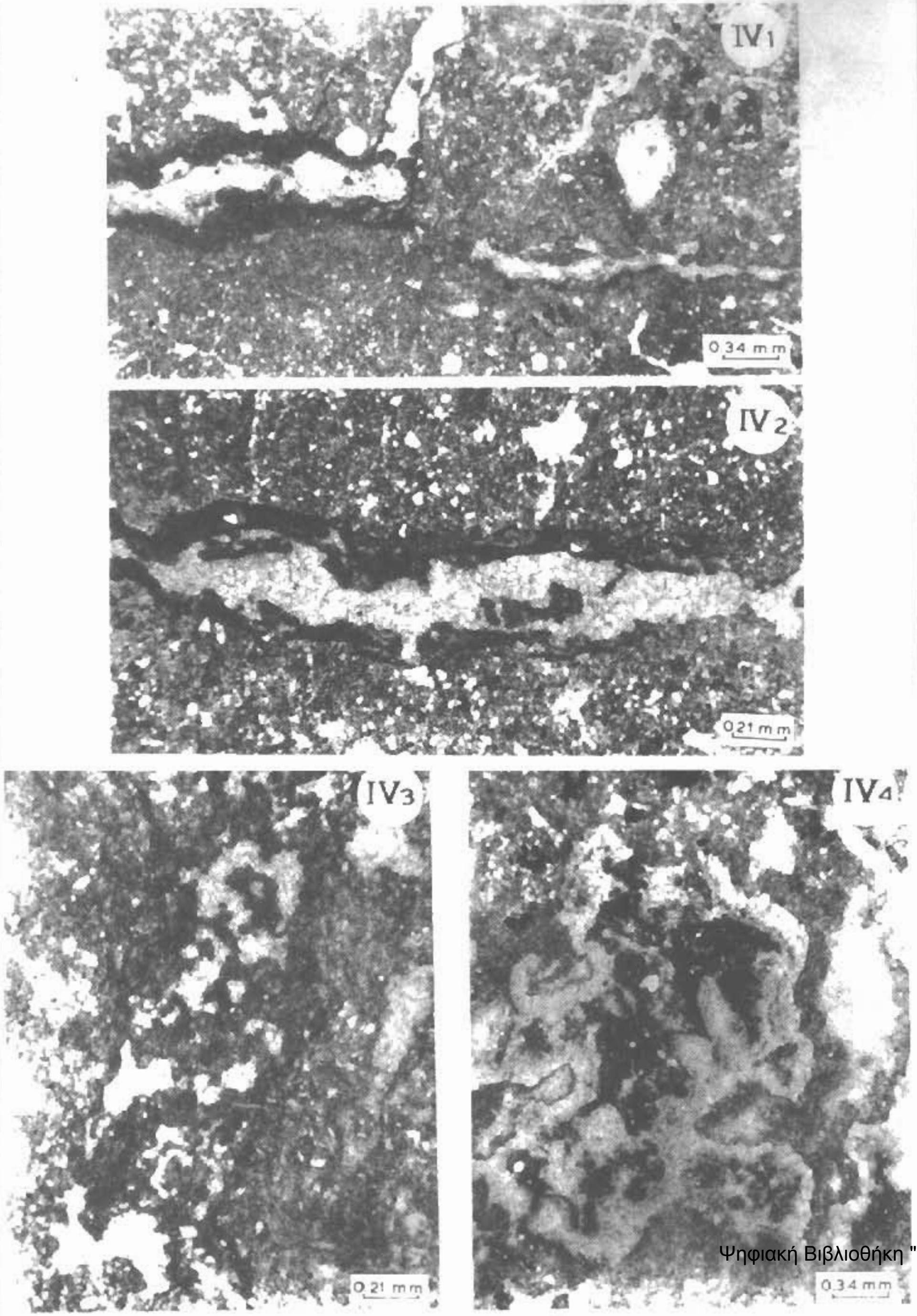

PLATE V – ΠΙΝΑΚΑΣ V