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CONODONT STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS AND STABLE ISOTOPE COMPOSITION OF THE TRIASSIC IN THE HELICON MOUNTAINS (BEOTIA, GREECE)

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A B S T R A C T

All Triassic stages -except the Scythian- have been discerned in the Helicon Mountains by microfacies- and biostratigraphic studies. In platy limestones of Anisian to Ladinian age 38 conodont species were recognized. Stable isotope compositions of limestones ($\delta^{13}C$, $\delta^{18}O$) are rather uniform throughout the more than 800m thick Triassic sequence. This is due to a syndiagenetic interaction with meteoric waters, which is also evident in the isotopic composition of different cements and Norian dolomitic limestones. Organic remains are sparse in the investigated limestones, rarely exceeding 200ppm C_{org}. Carbon isotope ratios of organic matter shift from -29°/₀₀ in Anisian and Ladinian deposits to -21°/₀₀ in Norian cryptalgallaminites. The distribution of $\delta^{13}C_{org}$ is discussed together with the results of GC-MS.

REGIONAL GEOLOGY AND STRATIGRAPHY

In the Helicon mountain range (fig.1) Triassic limestones were reported for the first time by RENZ (1905). Further investigations, mainly concerning the structural geology of the area (CELET & CLEMENT 1969, 1971, CELET et al. 1976, CLEMENT & MAURIN 1975) have contributed to the official geological maps (PAPA-STAMATIOU et al. 1971, BORNOVAS et al. 1984a, 1984b); however, Jurassic and Triassic rocks, except Late Jurassic volcanic intercalations, remained undivided. The results of microfacies studies on Triassic and Jurassic limestones in Central Greece have been published by CHRISTODOULOU & TSAILA MONOPOLIS (1975) and BASSOULET & GUERNET (1975). Further biostratigraphic investigations led also to new structural interpretations (JUX et al. 1987, KONERTZ 1987, SIMON 1987, STEUBER 1989).

Dark grey marbles of probably Paleozoic age are exposed in the vicinity of Agia Triada and represent the metamorphic basement of the Helicon mountain range. The Triassic and Jurassic sections above consist of more than 1800m thick limestones, terminating with ophiolites, radiolarites and nodular limestones of Tithonian age (SIMON & STEUBER 1990). Clastic deposits of Aptian-Cenomanian age continue the sedimentary record which was interrupted during the Early Cretaceous

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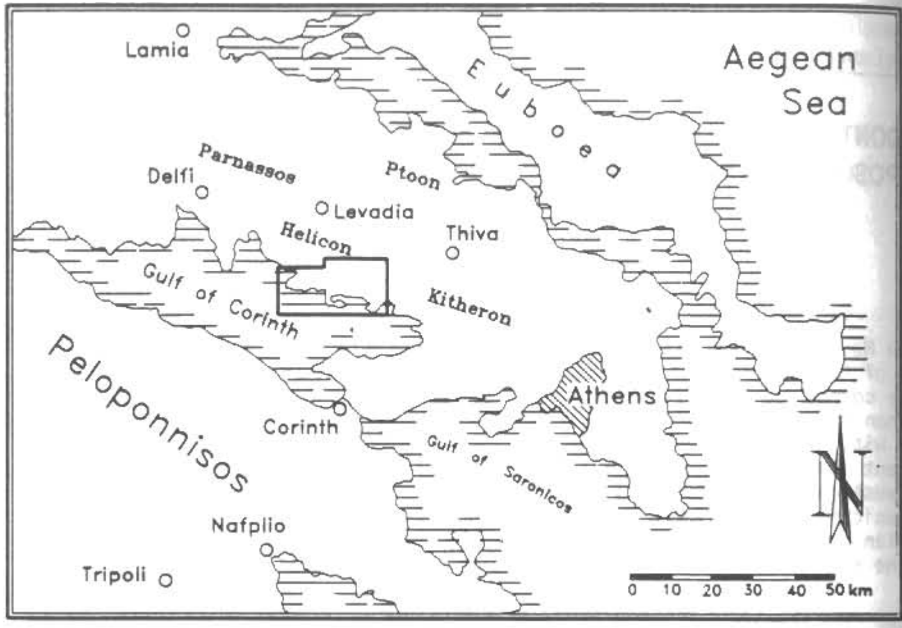

fig.1: Area of investigation.

due to the Eohellenian Orogeny. Transgressive Aptian sediments continue into Late Cretaceous limestones with intercalated bauxites. The latter indicate a Coniacian period of emersion. The Cretaceous-Tertiary boundary is marked by a change in lithofacies from calcareous to clastic, flysch-type deposits which yielded an Early Tertiary microflora (GOTZES 1989).

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE TRIASSIC SECTIONS

The oldest Triassic deposits which were recognized near the village of Agia Anna (fig.2) are thick bedded, reddish-grey limestones with *Meandrospira iulia* PREMOLI-SILVA and *Diplopora hexaster* PIA indicating an Anisian age (SIMON 1987). The abundance of *Tubiphytes obscurus* MASLOV and other incrustating algae evidence a reefal depositional environment.

Late Scythian volcanoclastics and red nodular limestones mentioned by BENDER (1962) from the adjacent Kitheron Mountains are missing in the area investigated. Similar sediments which were found at Domvrena Bay (fig.2) are of Tithonian age (SIMON & STEUBER 1990). However, in the Helicon Mountains the sedimentary record is continued by platy, dark grey, siliceous limestones which are exposed in a 30m thick section 2km to the north of Saranti (fig.2). Most of the samples contained abundant conodonts, from which more than 300 specimens have

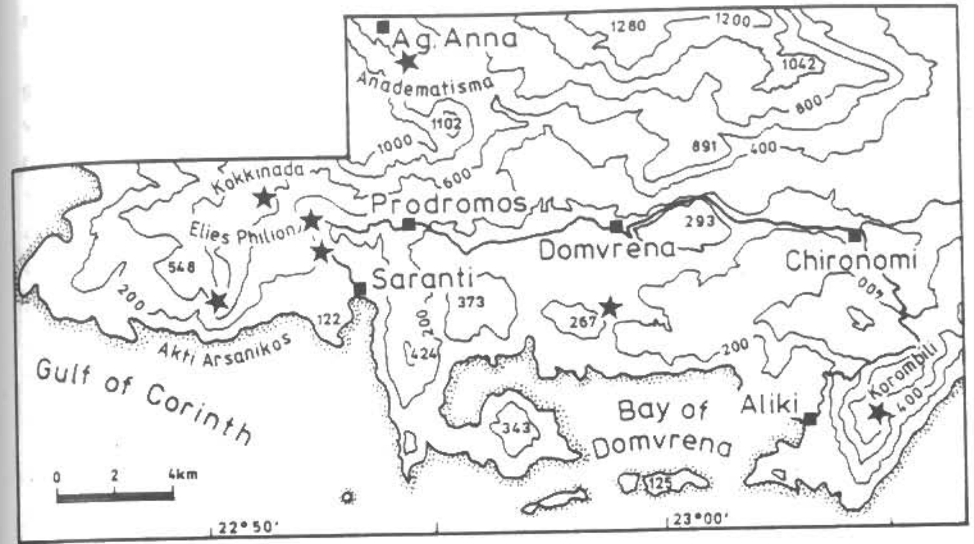

fig.2: Location of sampling sites.

been identified with the following species:

Chirodella dinodoides (TATGE)
Cornudina breviramulis (TATGE)
Cornudina tortilis KOZUR & MOSTLER
Cratognathodus posterognathus posterognathus MOSHER
Cratognathodus posterognathus angulatus (BUDUROV)
Didymodella alternata (MOSHER)
Diplododella bidentata (TATGE)
Enantiognathodus petraeviridis (HUCKRIEDE)
Enantiognathodus ziegleri (DIEBEL)
Gladigondolella tethydis (HUCKRIEDE)
Gondolella bakalovi (BUDUROV & STEFANOV)
Gondolella constricta MOSHER & CLARK
Gondolella eotrammeri KRYSTYN
Gondolella excelsa (MOSHER)
Gondolella trammeri (KOZUR)
Hibbardella lautissima (HUCKRIEDE)
Hibbardella magnidentata (TATGE)
Hibbardelloides acroforme (MOSHER & CLARK)
Hindeodella andrusovi KOZUR & MOSTLER
Hindeodella bogschi KOZUR & MOSTLER

Hindeodella multihamata HUCKRIEDE
Hindeodella pectiniformis (HUCKRIEDE)
Hindeodella spengleri spengleri (HUCKRIEDE)
Hindeodella spengleri sapanlii (GEDIK)
Hindeodella suevica (TATGE)
Lonchodina hungarica KOZUR & MOSTLER
Neohindeodella dropla (SPASOV & GANEV)
Neohindeodella triassica triassica (MOLLER)
Neohindeodella triassica aequidentata KOZUR & MOSTLER
Neohindeodella triassica riegeli (MOSHER)
*Neoplectospathodus müller*i KOZUR & MOSTLER
Neoplectospathodus sp.
Ozarkodina tortilis Tatge
Prioniodina mediocris (TATGE)
Prioniodina mülleri (TATGE)
Prioniodina pronoides (BUDUROV)
Prioniodina scolosculptura (MOSHER)
Prioniodina venusta (HUCKRIEDE)

Gondolella eotrammeri KRYSTYN and *G. trammeri* (KOZUR) attest an Illyrian-Langobardian age, the Ladinian-Anisian boundary being located in the lowermost part of the section. Compound elements largely outnumber the platform-conodonts, the latter mainly being represented by the stratigraphically insignificant *Gladigondolella tethydis* (HUCKRIEDE). Most of the platform-elements were unidentifieable juvenile forms (16 adult and 94 juvenile elements). *G. tethydis* (HUCKRIEDE) on the other hand was encountered with 70 adult and only 7 juvenile specimens. The stratigraphic distribution of conodonts from this section is described in more detail by STEUBER (1989).

Most layers of the fossiliferous flagstones are composed of graded bedded intrasparites at the base and of intramicrites and micrites with radiolarians at the top. Basal *Tubiphytes*-intraclasts are interpreted as reefal debris deposited in a hemipelagic environment. A decrease of this allochthonous carbonate input from the nearby shelf-platform led to the dominance of pelagic sedimentation and the enrichment of radiolarians and conodonts.

Tubiphytes-limestones of Ladinian age are exposed at the Kokkinada anticline 3km to the north of Saranti (fig.2). These light grey, massive limestones are strongly recrystallized, but Solenoporaceae, Sphinctozoa and incrusting algae still indicate a reefal heritage. Few foraminifera (*Ammobaculites* sp., *Endothyra* sp., *Endothyranella* sp., *Ophtalmidium martanum* (FARINACCI) and the conodonts *Chirodella dinodoides* (TATGE) and *Neohindeodella triassica triassica* (MOLLER) have been recognized. Similar limestones with an identical microfauna

and -facies have been encountered 3km southeast of the Domvrena village (fig.2).

The Triassic section is continued 1km north of Saranti, where light grey, thick bedded limestones have been sampled. Biosparites with *Tubiphytes* prevail in the lower part of this section, whereas intrapelmicrites and microbrecias with abundant internal sediments are concentrated in the upper part. They indicate a shallow lagoonal environment which is also reflected by the occurence of decapod coproliths (*Parafavreina thoronetensis* BROENNIMANN et al.) and abundant algae (*Cayeuxia* sp.). Among the rather diverse foraminifera-assemblage are *Agathammina austroalpina* KRISTAN-TOLLMANN & TOLLMANN, *Agathammina iranica* ZANINETTI et al., *Diplotremina astrofimbriata* KRISTAN-TOLLMANN, *Glomospira sinensis* HO, and *Trochammina alpina* KRISTAN-TOLLMANN, which attest a Carnian age. During this time, sporadic phases of emersion led to the formation of meniscus-cements. Red coloured internal sediments filled fissures that apparently opened before the formation of stylolites.

During the Norian stage Lofer-type dolomitic limestones accumulated. Such sequences are now exposed in an undisturbed section, more than 250m thick, at Akti Arsanikos to the west of Saranti (fig.2). At the base brownish-grey limestones with interbedded *Conchodus*- and gastropod coquinas prevail, while the major part of the section consists of cyclothems with dolomitic cryptalgallaminites, white sugargrained dolomitic limestones and dolomitic *Conchodus*-limestones. In the uppermost part thickbedded limestones reoccur, but *Conchodus* finds are missing. In contrast to the Lofer-cyclothems of the Alpine Triassic (FISCHER 1964) also regressive parts of the sedimentary cycles are preserved in the Helicon Mountains. Late Triassic deposits of a similar facies were described from the Olympus (POMONI-PAPAIOANNOU et al. 1986), the Peloponnisus (KALPAKIS & LEKKAS 1982) and Hydra (RICHTER & FÜCHTBAUER 1981).

The microfauna and -flora of this section comprises *Thaumatoporella parvovesiculifer* (RAINERI), dasycladaceae and the foraminifera *Agathammina austroalpina* KRISTAN-TOLLMANN & TOLLMANN, *Glomospira amplificata* KRISTAN-TOLLMAN, *Involutina sinuosa pragsoides* (OBERHAUSER) and *Trochammina almtalensis* KOEHN-ZANINETTI. Even a single conodont element of the species *Metapolygnathus abneptis* (HUCKRIEDE) was encountered in a dolomitic *Conchodus*-limestone.

The Triassic sequence is terminated by grey, bedded , lagoonal limestones that form the Korombili summit, bordering the Bay of Domvrena in the East (fig.2). This section was investigated by SIMON (1987); it links the Norian sub- and intertidal facies to Liassic lagoonal deposits (SIMON & STEUBER 1990).

The standard section (fig.3) of the Triassic sequence in the Helicon Mountains, which resulted from the outcrops mentioned above, amounts to more than 800m. Although there is no evidence for facies transition between the Anisian and Ladinian reefal and hemipelagic deposits, the section is assumed to be complete.

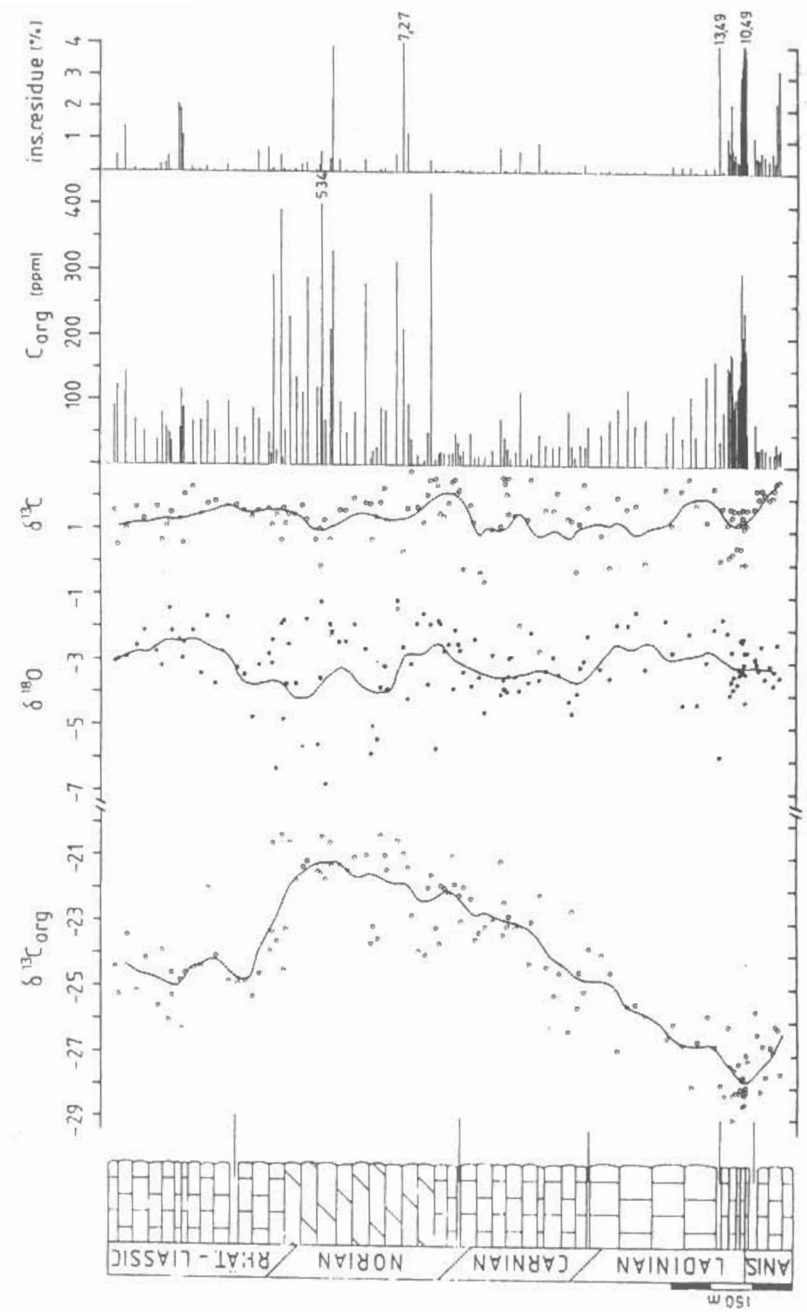

fig.3: Standard section of the Triassic in the Helicon mountain range.

ISOTOPIC ($\delta^{13}C$, $\delta^{18}O$) COMPOSITION OF CARBONATES

Mass spectrometric determinations of stable isotope ratios have been performed on the CO_2 liberated by H_3PO_4 digestion of carbonate rock samples. The -values are referred as per mill deviations from the PDB-standard. Whole rock data are supplemented by analyses of individual cements. Calcite and dolomite of the Norian dolomitic limestones have been separated by different reaction times as proposed by EPSTEIN et al. (1964). No correction concerning different oxygen isotope fractionation factors during acid digestion of dolomite have been employed because the ^{18}O-enrichment in respect to calcite appears to be negligible (FRIEDMAN & O'NEILL 1977, AHARON et al. 1987).

The whole rock isotopic composition of the Triassic limestones was found to vary between -3°/oo to +3°/oo $\delta^{13}C$ and -1°/oo to -7°/oo $\delta^{18}O$, revealing no distinctive trend with stratigraphic age (fig.3). A more pronounced scatter of $\delta^{18}O$

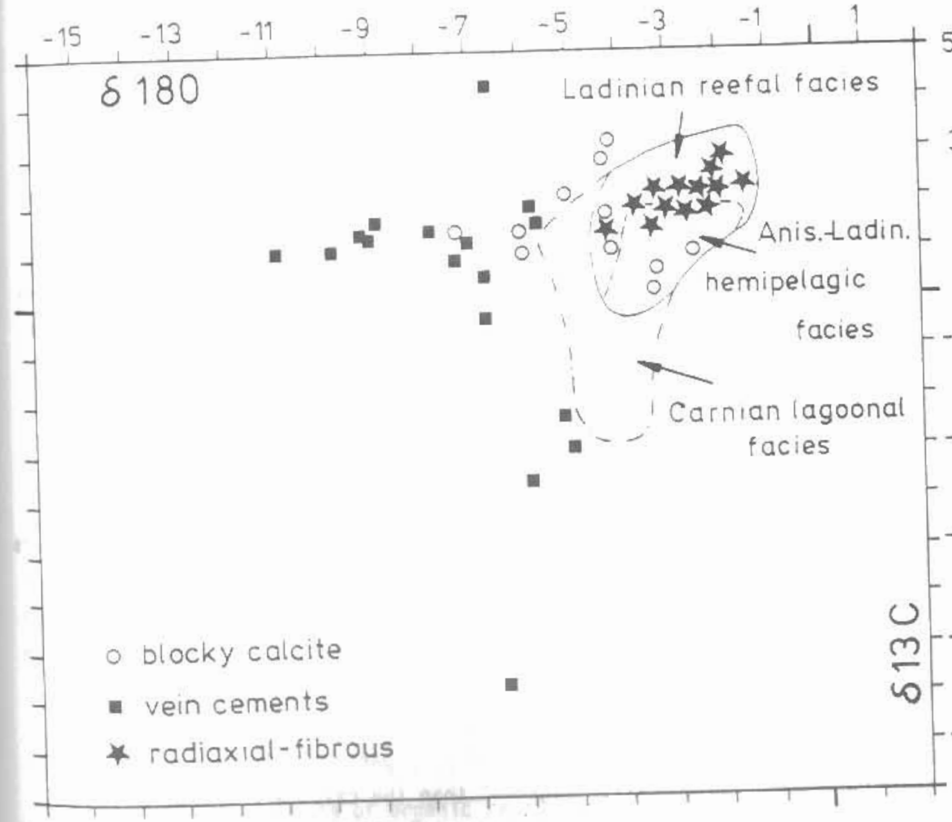

fig.4: Isotopic composition of various cements compared with whole rock data.

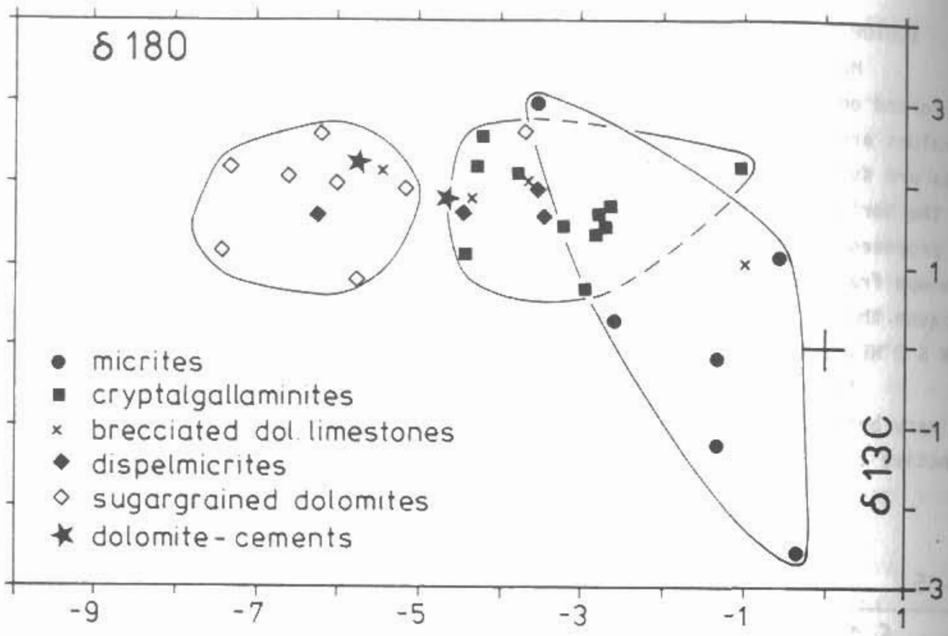

fig.5: Isotopic composition of Norian dolomitic limestones, dolomite fraction.

is obvious in the Norian Lofer-type dolomitic limestones, whereas negative $\delta^{13}C$-values are characteristic for the Norian dolomitic as well as for the Carnian lagoonal limestones. It should be noted, that these values fit rather well with the "isotope logs" presented by HOLSER et al. (1989) from the Permian/Triassic boundary of the Austrian Alps.

However, the oxygen isotope ratios seem to depict a diagenetic interaction with meteoric waters. The isotope ratios of both blocky calcitic and vein cements are well separated from those of the whole rock samples (fig.4). Both reveal a depletion in ^{13}C and ^{18}O, the calcitic vein cements being the most depleted ones. Thus, the shift to isotopically "lighter" whole rock composition appears to depend considerably on the amount of diagenetic cements. Radiaxial fibrous cements which are abundant in the Ladinian reefal deposits were found to be near to isotopic equilibrium with normal sea water. They obviously seem to originate from recrystallized former aragonitic cements (BATHURST 1971, ROSS et al. 1975).

As mentioned above, the Norian dolomitic limestones yielded the most negative oxygen isotope ratios (fig.3,5). This is particularly true for the dolomite fraction, being isotopically "lighter" than the calcite fraction in most samples. The abundant birdseye sparite in cryptalgallaminites consists of dolomite whereas the matrix is less dolomitic. Pure dolomites, however, have not been encountered at Akti Arsanikos; even in white,sugargrained dolomitic limestones Mg/Ca molar ratios do not exceed 0.86.

In contrast to the interpretation of similar stable isotope data obtained by GÜKDAG (1974), a diagenetic interaction with meteoric waters appears to be responsible for the "light" oxygen isotope ratios. Most probably, dolomitisation was caused by the percolation of mixed marine and fresh formation waters during early diagenesis. In accordance with the "mixing zone" model (FOLK & LAND 1975), magnesium may have been contributed by cyanophyceans (GEBELEIN & HOFFMANN 1971). The isotopic record presents no evidence for hypersaline conditions during diagenesis or deposition.

INSOLUBLE RESIDUES AND ORGANIC MATTER CONTENT

The acis insoluble residues consist mainly of clay-minerals and silty quartz. Higher amounts of residues in the Anisian and Ladinian hemipelagic limestones (fig.3) are due to the skeletal remains of radiolarians and siliceous sponge spicules and to an increased input of detritial clay and silt. Remarkable low amounts of insolubles, rarely exceeding 0.1% were found in the Late Ladinian and Carnian sections, whereas the Norian dolomitic limestones contain up to 7.3%.

Organic matter is sparse throughout the sections, particularly in the Late Carnian to Early Norian lagoonal limestones, where C_{org}-yields are less than 50ppm. Up to 500ppm C_{org} was found in the Lofer-type dolomitic limestones, corresponding to the higher amounts of insoluble residues.

MICROSCOPIC AND GASCHROMATOGRAPHIC INVESTIGATIONS OF ORGANIC MATTER

For microscopic studies of organic remains selected samples were treated with fluoric acids. Nevertheless, most samples yielded only amorphous bitumina and kerogens. Fragments of higher plants were recorded in samples from the Anisian-Ladinian platy limestones. Vitrinite reflexions could only be measured on two specimens, yielding R_{max}-values of 1.3-1.5%.

The presence of saturated hydrocarbons in the insoluble residues as revealed by GC-MS (fig.6) indicate moderate burial temperatures for the Triassic limestones. Apparently they did not subside below the limits of hydrocarbon generation. This is confirmed by the degree of conodont colour alteration. Hopanes, which are reliable biological markers for bacteria and cyanobacteria (OURISSON et al. 1979) were identified from Norian cryptalgallaminites. These results show, that GC-MS studies can be a powerful tool to investigate sedimentary rocks even with extremely low amounts of organic remains.

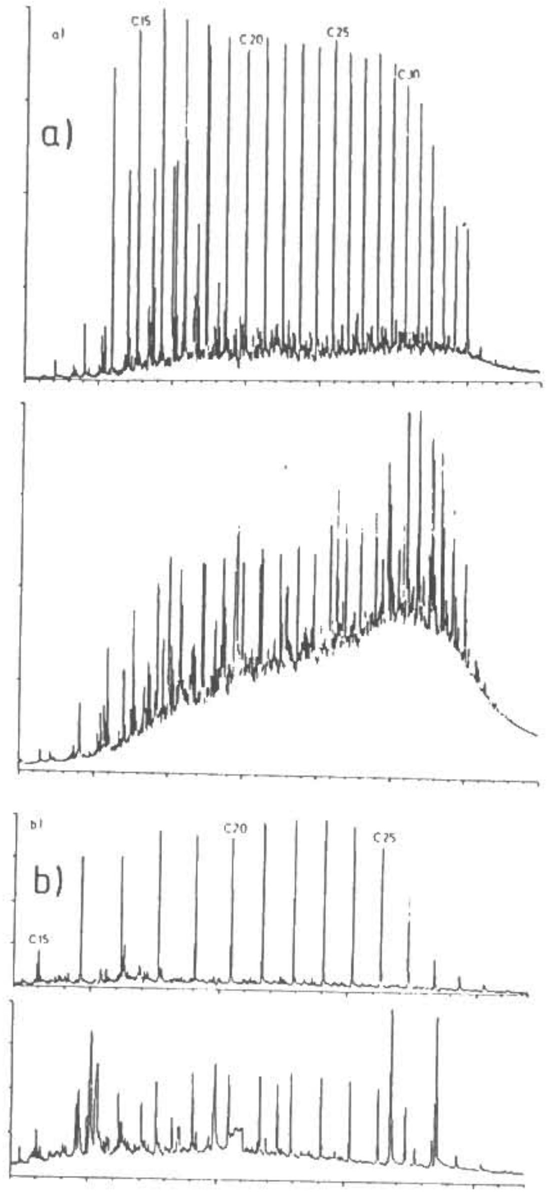

fig.6: Gaschromatograms and massfragmentograms of a Norian cryptalgallaminite (a) and an Early Ladinian platy limestone (b).

CARBON ISOTOPIC COMPOSITION OF ORGANIC MATTER

Stable isotope ratios of organic carbon have been determined on CO_2 collected from the quantitative combustion of washed and dried insoluble residues. The reproduceability of the mass-spectrometric analyses was 0.1°/₀₀, including sample preparation.

There is a pronounced shift of $\delta^{13}C_{org}$, ranging between -29°/₀₀ and -27°/₀₀ in Anisian-Ladinian limestones to -21°/₀₀ in the Norian dolomitic limestones (fig.3). The transition from dolomitic Lofer-cyclothems to the overlying lagoonal limestones corresponds with a marked decrease of $\delta^{13}C_{org}$-values to ca.

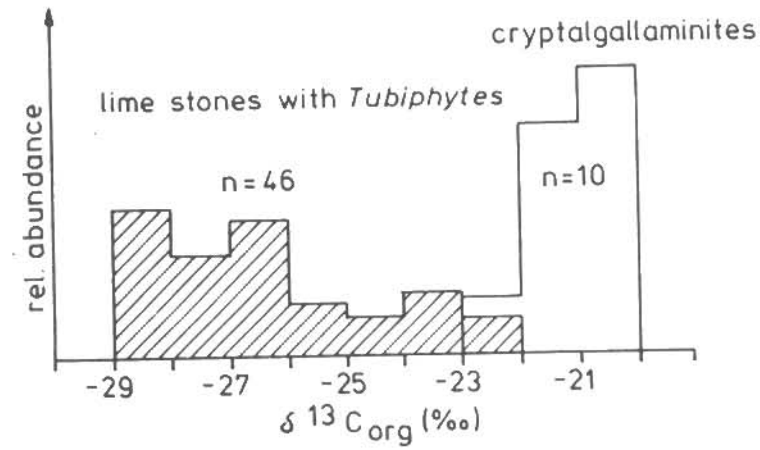

fig.7: $\delta^{13}C_{org}$-values of cryptalgallaminites and limestones with *Tubiphytes*.

-25°/₀₀.

Isotopically "heavy" organic matter, significant for the cryptalgallaminites (fig.7), was also found in recent stromatoliths (BEHRENS & FRISHMAN 1971). The lagoonal rocks of Upper Carnian age contain organic carbon of relatively "heavy" isotopic composition as well, corresponding to very low amounts of insoluble residues. This suggests a reduced input of terrigenous organic matter. The observed $\delta^{13}C_{org}$-values fit into the range of -23 to -12°/₀₀, reported from modern red and green algae (SMITH & EPSTEIN 1971). More negative values of the Middle Triassic limestones on the other hand are a characteristic of terrestrial C3-plants (BENDER 1971). This group, to which belong most gymnosperms, had already been abundant in Triassic times. Thus, low $\delta^{13}C_{org}$-values of the

Anisian-Ladinian flagstones are in accordance with abundant fragments of higher plants in residues of these limestones. Apparently, this terrigenous input decreased in Middle Triassic times, which is -as mentioned above- also evidenced by rather low contents of insolubles. Organic matter preserved in the Norian dolomitic limestones is obviously derived from cynophyceans; contributions of C3-plants are not recorded in the $\delta^{13}C_{org}$-values. The shift of carbon isotope ratios during the Late Norian indicates an increased share of terrigenous organic matter and coincides with the end of the dolomitic facies. It is probably due to different continental drainage systems.

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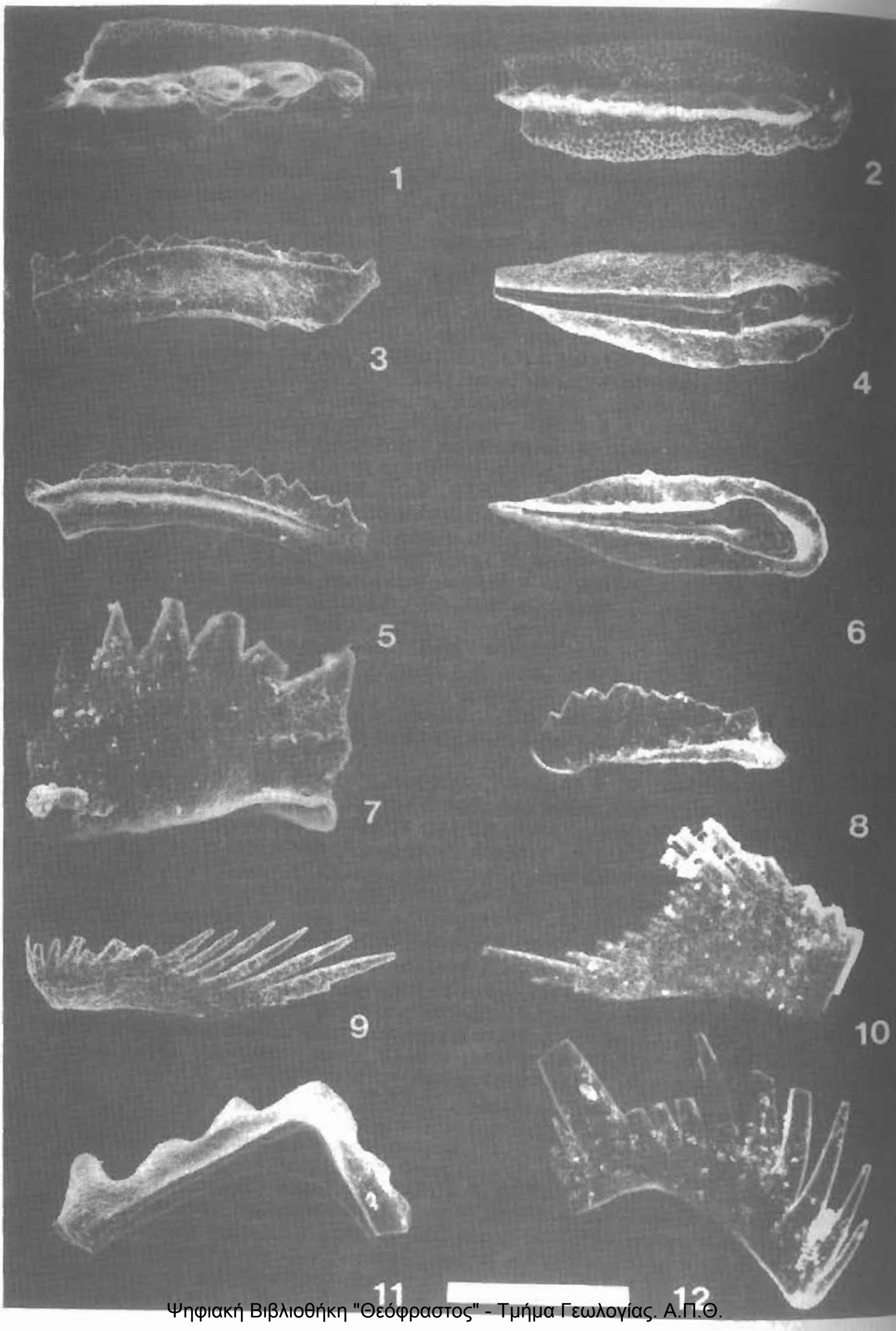
PLATE 1

fig.1: *Gondolella bakalovi* (BUDUROV & STEFANOV), scale 165µm; fig.2: *G. constricta* MOSHER & CLARK, scale 200µm; figs.3,4: *G. trammeri* (KOZUR), scale 230µm; figs.5,6: *G. eotrammeri* KRYSTYN, scale 315µm; fig.7: *G. excelsa* (MOSHER), scale 105µm; fig.8: *G. excelsa* (MOSHER), scale 370µm; fig.9: *Neoplectospathodus mülleri* KOZUR & MOSTLER, scale 140µm; fig.10: *Neoplectospathodus* sp., scale 130µm; fig.11: *Cratognathodus posterognathus angulatus* (BUDUROV), scale 210µm; fig.12: *Hindeodella pectiniformis* (HUCKRIEDE), scale 185µm.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