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SEDIMENTOLOGICAL CHARACTERISTICS OF UPPER TRIASSIC (CORDEVOLIAN) CIRCULAR QUIET WATER CORAL BIOHERMS IN WESTERN SLOVENIA, NORTHWESTERN YUGOSLAVIA

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ABSTRACT

Six circular-shaped quiet water coral bioherms of Upper Triassic (Cordevolian) age, ranging from 25 to 140 meters in height and from 50 to 180 meters in diameter, outcrop 20 kilometers north-northwest of Idrija in western Slovenia, northwestern Yugoslavia. Within the biohermal depositional area two distinctive lithological and faunal associations have been identified. These are: 1. the biohermal core and marginal breccias which pass into, 2. surrounding bedded biopelmicritic limestones. The biohermal cores are composed primarily of corals and consist of various biolithites and biopelmicritic limestones. A relatively quiet water depositional environment is suggested for these bioherms. This interpretation is reinforced by the occurrence of only modest accumulations of marginal breccias, and the occurrence of layered pelbiomicritic limestones between individual bioherms. These circular bioherms are surrounded and embedded in a sequence of interbedded sandstones and shales.

INTRODUCTION

Circular-shaped, quiet water coral bioherms of Upper Triassic age (Cordevolian) outcrop in an area 20 kilometers northwest of Idrija (location of a famous mercury mine), in western Slovenia, northwestern Yugoslavia (Fig. 1A).

Within an outcrop area 500 by 400 meters, six large circular coral bioherms have been mapped (Fig. 1B). At ground surface they appear as regular circular-shaped calcareous structures connected at various levels with either breccias or bedded limestones. The largest bioherm is approximately 180 meters in diameter and 140 meters in height, whereas the smallest bioherm is 50 meters in diameter and about 25 meters in height. The angle of depositional slope averages 65 degrees. Some bioherms exposed on the steep slopes of Kojca Hill stand out conspicuously from the surrounding sediments (Fig. 2). At this location there is very little associated reef talus and we assume that these bioherms are preserved *in toto*.

For this discussion the two largest bioherms (Fig. 1B) and the surrounding sediments have been described in detail, with particular attention being paid to facies relationships and faunal distributions.

STRATIGRAPHIC SETTING

The first geologist to work in this area was M. V. Lipold (1857). Additional work, mainly of a stratigraphic and tectonic nature, was done by Kossmat (1910) and Berceetal (1959). However, it has only been since 1977 when Placer *et al.*, recognized these structures as coral bioherms, and noted the basic stratigraphic and facies relationships.

The stratigraphic position of these coral bioherms is shown in Figure 3. The bioherms occur in the upper portion of the Upper Triassic Pseudozilian Formation. In this region the Pseudozilian Formation is at least 1000 meters in thickness, and consists of laminated black shales, sandstones and pyroclastics with lenses of layered black limestones, and numerous reef-knolls and patch-reefs. The Pseudozilian Formation is underlain by upper Middle Triassic (Ladinian) igneous rocks (keratophyres and diabases), and associated volcanic tuffs.

In a reef-knoll several meters in diameter, and

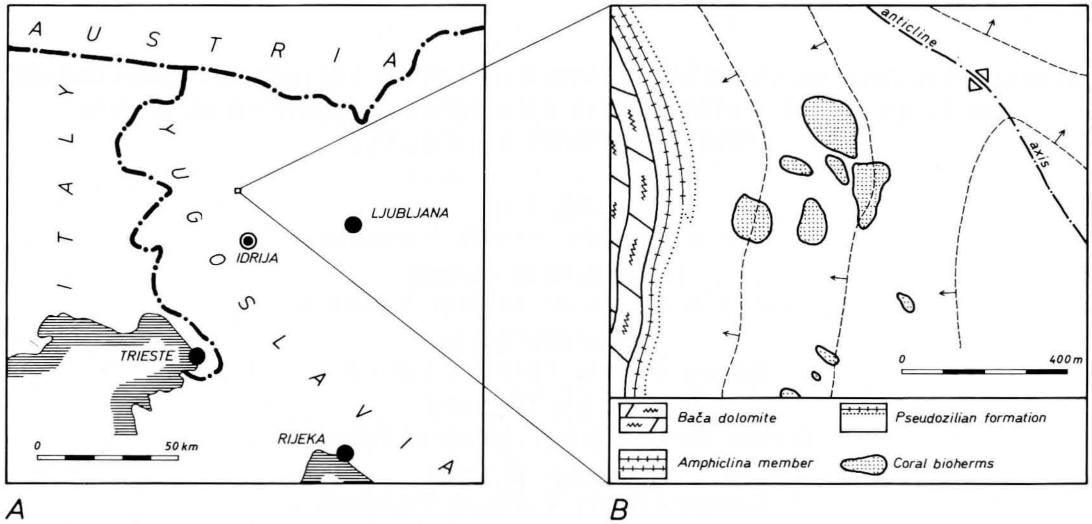


FIG. 1.—Maps locating the studied area in western Slovenia, northwestern Yugoslavia. A. Index map showing area of bioherm outcrops. B. Generalized geological map showing the distribution and size of the studied circular, quiet water coral bioherms.

located in beds below the circular coral bioherms, specimens of the coral *Margarophyllia michaelis* Volz have been identified (Fig. 4A). This coral species is characteristic of the Upper Triassic Carnian Stage (lower Cordevolian). The lower and central portions of the bioherm's reef framework contains corals which are well known from classical Triassic (Cordevolian) beds at St. Cassian in Tyrol (Volz, 1896; Leonardi, 1967). Several species of biohermal corals do have longer stratigraphic ranges, while other biohermal corals such as the bushy form *Hexastrea fritschi* Volz, and the solitary corals *Margarophyllis crenata* Volz (Fig. 4B) and *Myriophyllum dichotomum* (Loretz) (Fig. 4C), are found only in Cordevolian beds (see Table 1).

Beds in the uppermost portion of the bioherms contain coral specimens so strongly recrystallized they cannot be properly identified.

Approximately 70 meters above the highest coral bioherms are a series of limestones and limestone conglomerates designated as the *Amphiclina* Member. Conodonts retrieved from these beds indicate that this interval is of highest Carnian age (Tuvalian), as reported by Placer *et al.* (1977).

On the basis of the above biostratigraphical data we have concluded that growth of the circular coral bioherms began in Cordevolian time and ended in Julian time (Fig. 3).

REEF ORGANISMS

The primary reef building organisms of the Pseudozilian bioherms are colonial and solitary corals. Eight coral species have been identified and their stratigraphic ranges shown in Table 1. The skeletal framework of the bioherms is built by these ramose colonial and solitary coral species. All of these corals are considered to have been rather fragile and most suited to live only within quiet water environments.

Other accessory organisms do occur within the bioherms, and these consist of both skeletal and non-skeletal algae, planktic foraminifers, hydrozoans, and molluscs (pelecypods). It should be noted however that most of these are strongly recrystallized and only rarely does the state of preservation allow accurate identification. Undoubtedly, other organisms were more common while

FIG. 2.—Outcrop photograph of the eastern slope of Kojca Hill showing prominent biohermal exposures.

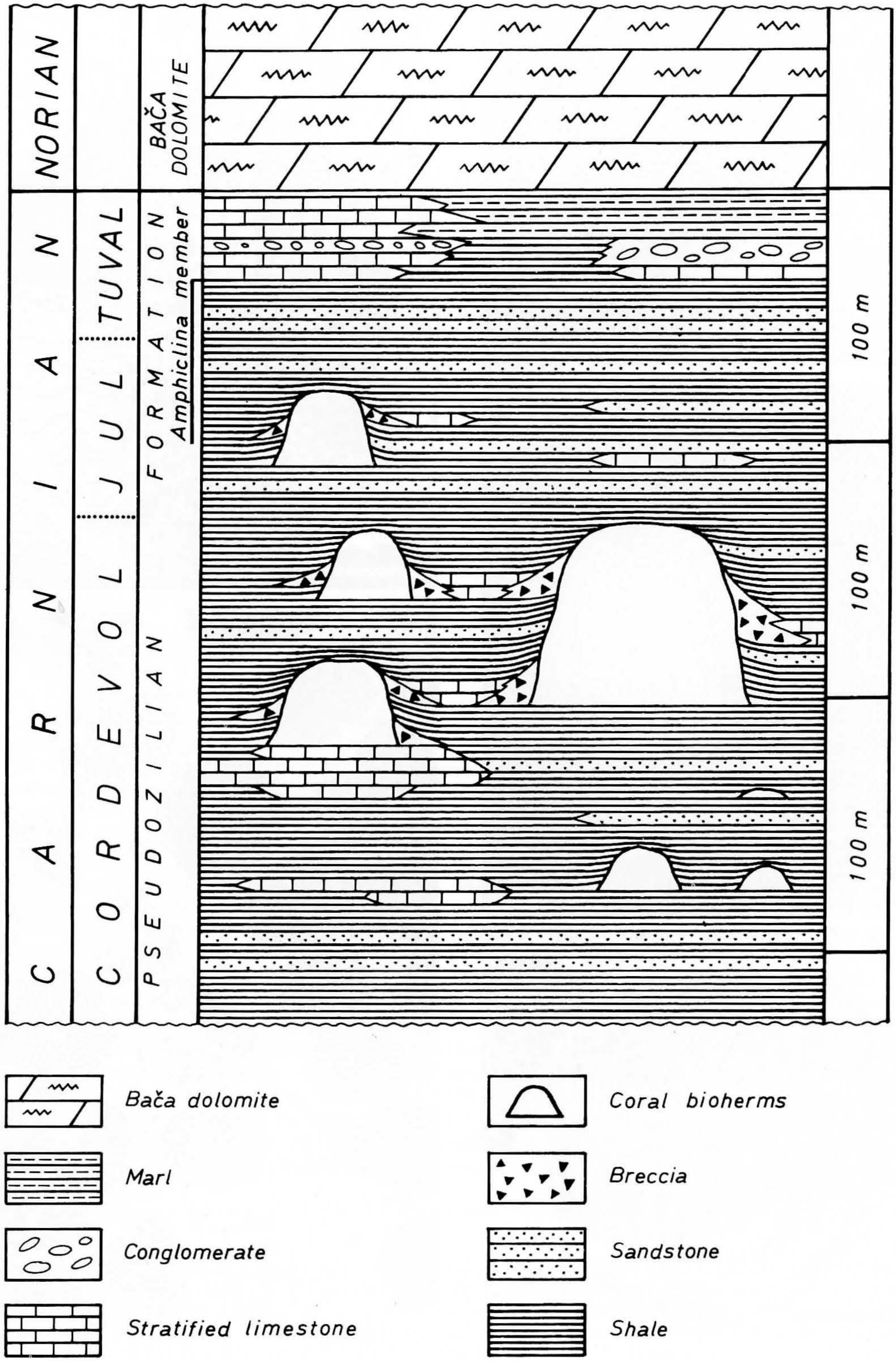
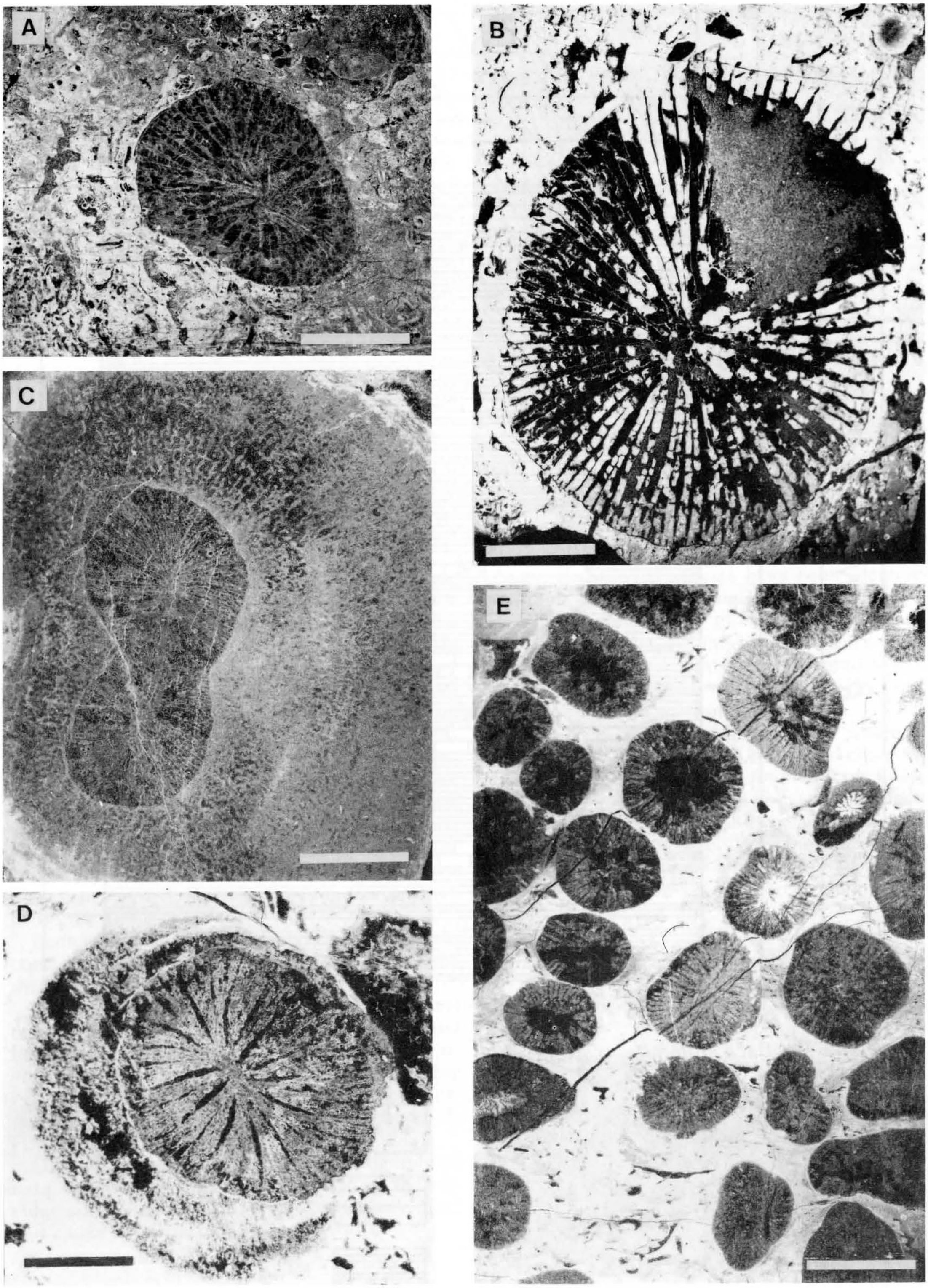


FIG. 3.—Stratigraphic column showing regional time-stratigraphic framework and the intervals of biohermal development.


A
B
C
D
E

the bioherms were growing, but these cannot be determined after severe diagenetic alterations. A complete listing of accessory species is not yet available.

LITHOFACIES

Within the Cordevolian biohermal interval two lithological associations have been recognized. They are: 1. rocks that make up the bioherms, and 2. those sediments surrounding the bioherms. Of the biohermal rocks, we recognize both a core facies and a facies of marginal breccias which pass into the surrounding bedded limestones.

Biohermal Cores

The fundamental characteristic of biohermal core rock is the dominance of *in situ* coral frame builders. However, the abundance of frame building corals varies appreciably. For example, along the marginal portion of the largest bioherm (Fig. 1B), corals may make up to 40 percent of the total biomass, while in other parts of various bioherms, corals may only make up a few percent of the total mass. Actual corallites are relatively narrow and generally attain a height of 40 centimeters, but some corallites up to 80 centimeters in height have been observed.

Among core organogenic limestones both biolithites and bioclastic limestones can be distinguished. The biolithites are composed chiefly of corals and hydrozoans, both of which may be commonly overgrown with non-skeletal algae (Fig. 5A and B). Whereas bioclastic limestones are made up of rich associations of the fragmented remains of organisms that lived on the bioherms. These include debris of corals, hydrozoans, molluscs (gastropods), and echinoderms. Bioclastic fragments are, as a rule, not well-sorted and rounded, but may be encrusted with non-skeletal algae. According to bioclast size, the rocks may be termed either calcirudites or calcarenites. In addition to various size bioclasts, numerous peloids, small oncolites, and rare mud intraclasts may be observed. Rock matrix is usually micrite, and only occasionally has this been diagenetically altered to microspar. According to Dunham's (1962) carbonate classification these rocks would be referred to skeletal/peloidal/intraclastic wackestones and packstones. The rocks of the biohermal cores appear to have been deposited in relatively quiet water environments, especially since their water energy index value does not exceed a maximum of II (Plumley *et al.,* 1962). A higher water energy value is only suggested for those limestones containing oncolites (Fig. 5E). Some oncolites attain a diameter of 4 centimeters.

TABLE 1.—STRATIGRAPHIC RANGES OF BIOHERMAL CORALS

Species	Stratigraphic Ranges		
	Ladinian	Lower Cordevolian	Upper Cordevolian
Colonial Corals:			
Margarosmilia zieteni Klipstein		xxxxxxxxxx	xxxxxxxxxx
Margarosmilia confluens Münster	xxxxxxx	xxxxxxxxxx	xxxxxxxxxx
Hexastraea fritschi Volz		xxxxxxxxxx	
Volzeia badiotica (Volz) (Fig. 4D)	xxxxxxx	xxxxxxxxxx	
Solitary Corals:			
Margarophyllia michaelis Volz (Fig. 4A)		xxxxxxxxxx	
Margarophyllia capitata Münster (Fig. 4E)	xxxxxxx	xxxxxxxxxx	xxxxxxxxxx
Margarophyllia crenata Volz (Fig. 4B)		xxxxxxxxxx	xxxxxxxxxx
Myriophyllum dichotomum (Loretz) (Fig. 4C)		xxxxxxxxxx	xxxxxxxxxx

The micritic matrix of the biohermal cores is often disrupted by irregular burrows up to a centimeter in diameter. Probable soft-bodied sediment ingesting organisms thoroughly bioturbated the biohermal core micrites. These burrows may be filled with sparry calcite cement and micritic sediment, or only filled with coarse mosaics of sparry calcite. Some relatively large vugs, up to

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FIG. 4.—Thin-section photomicrographs of various coral species from the Upper Triassic (Cordevolian) biohermal facies; bar scale 5 mm in length. A. Transverse section of the corallum of the solitary coral *Margarophyllia michaelis* Volz. B. Transverse section of the corallum of the solitary coral *M. crenata* Volz. C. Transverse section of a bicentric corallum *Myriophyllum dichotomum* (Loretz) encrusted with hydrozoan material. D. Transverse section of corallites of the phaceloid colonial coral *Volzia badiotica* (Volz). E. Transverse section of the corallum of the solitary coral *Margarophyllia capitata* Münster.

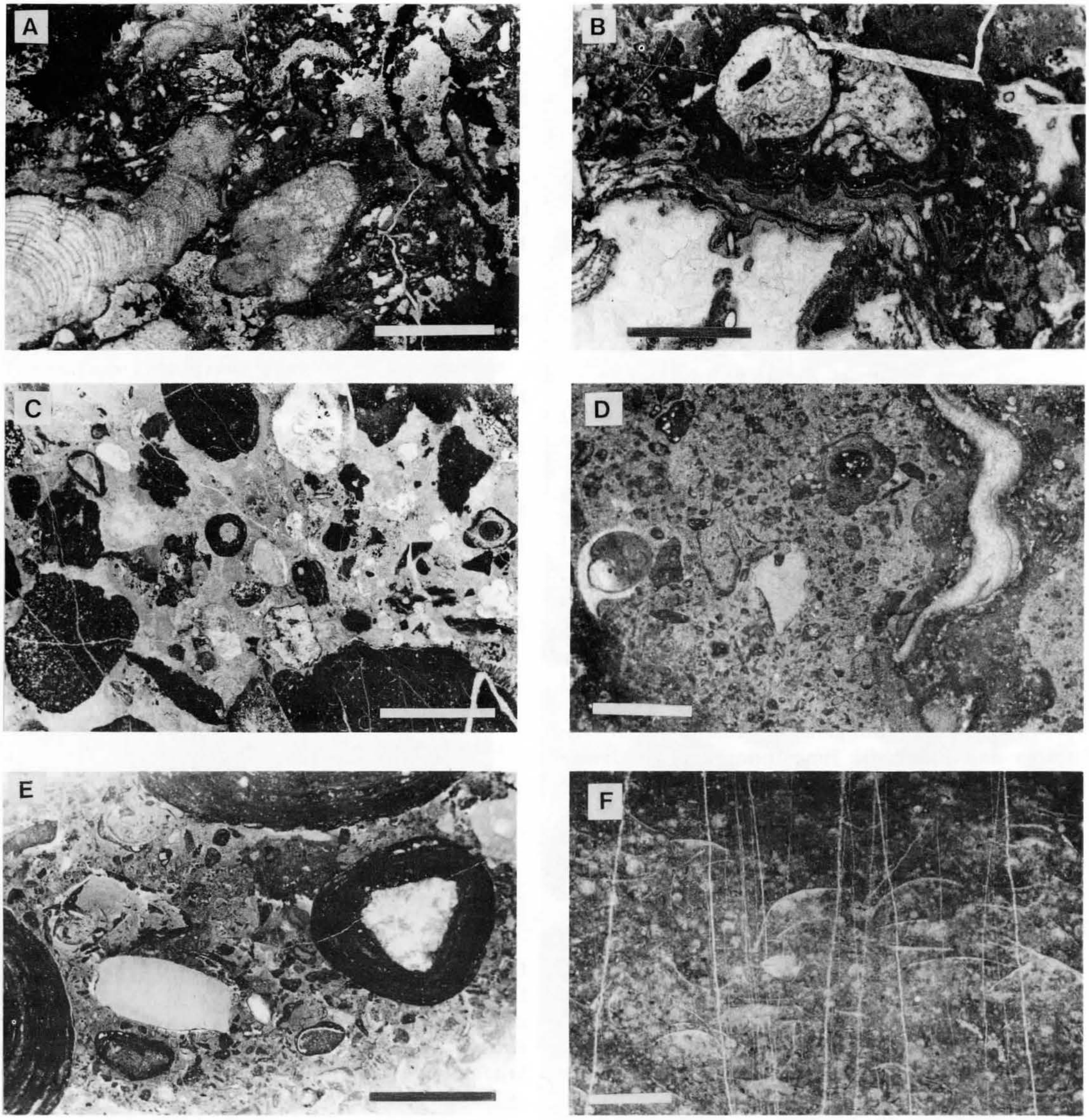

FIG. 5.—Thin-section photomicrographs of various rock fabrics encountered within the coral biohermal facies. A. Typical biolithite showing non-skeletal algal overgrowths on hydrozoans; bar scale 5 mm. B. Recrystallized corallites overgrown with non-skeletal algal coatings, and interspaces filled with sparry calcite; bar scale 5 mm. C. Fine-grained calcirudite composed of a mixture of muddy intraclasts and skeletal fragments; bar scale 1 cm. D. Recrystallized muddy intraclastic biomicrite with some shell debris overgrown with non-skeletal algal coatings; bar scale 2 mm. E. Typical oncolitic structures; rocks contain intraclasts, peloids, and skeletal grains (mainly mollusc fragments); bar scale 1 cm. F. A marly biomicritic limestone from one of the carbonate lenses intercalated within the shales surrounding the bioherms. Fossils consist mainly of thin-shelled molluscan debris along with calcitized radiolarian skeletons; bar scale 1 mm.

several centimeters in length, and closely resembling "stromotactis," are usually filled with geopetal internal sediment.

The carbonates of the biohermal cores also contain trace amounts of authigenic quartz, chert, and pyrite. At a later diagenetic phase these carbonates were recrystallized and lightly and selectively dolomitized.

Marginal Breccias Transitional to Bedded Limestones

Marginal breccias are only poorly represented on the circular bioherms. They are better represented on the biohermal fore-slopes, and in some cases, in the channels between the bioherms. The breccias are poor-to-moderately-sorted with clasts averaging about 2 centimeters in diameter. The clasts consist of pelmicrites and biomicrites, and large organism fragments. In some instances bioclasts are circumscribed with coatings of non-skeletal algae. Terrigenous grains of quartz and chert up to 4 millimeters in diameter can also be present in these breccias. Cement usually consists of micrite or microspar, clay minerals, and some pyrite. In some occurrences the cement may be slightly dolomitized.

Vugs also occur quite commonly within these breccias, these too are of "stromatactis" type and are usually filled with internal sediment.

Along the margins of these bioherms some clasts may be deformed. Here and in the areas between the bioherms, the breccias pass into bedded limestones up to 2 meters in thickness. These limestones usually pinch out rapidly in all directions. They are classified as slightly-washed biopelmicrites, some contain pelmicritic intraclasts up to 1 centimeter in diameter. Evidence of bioturbation also occurs within these sediments, and among fossils, foraminifers and thin-shelled molluscs are common while calcitized radiolarians are very rare.

Surrounding Sediments

The circular coral bioherms are surrounded by grey to dark-grey clastic sediments consisting of an interbedded sequence of sand and shale layers. In the lower portion of the formation laminated shales predominate, but interbedded with them are thin beds of fine-grained sandstone. These sandstones may be cross-laminated, and in places are ripple-marked. The amount of sandstone within the section increases upward. Some sandstone beds may even display poor graded-bedding, and these are usually overlain with intervals where bedding may be parallel, inclined, or wavy. Some ripple marks can be found on their upper surfaces. Interbedded with the sandstones are beds of laminated shale. In the upper portion of this sequence the shales are rather conspicuously bioturbated. In places these shales are cut by small erosional channels up to 15 centimeters in depth and 2 meters in width. The channels are filled with coarse-grained sandstone, which in places may be conglomeratic. These conglomerates may contain large intraformational flat pebbles of shale up to 10 centimeters in diameter.

The sandstones are very fine to coarse-grained, and moderately well-sorted. Terrigenous grains consist of poly- and monocrystalline quartz, feldspar, lithic fragments of granitic and extrusive rocks, quartzites, sandstones, schists, and tuffs. These terrigenous grains are bound together with matrix and cement. The major portion of the matrix is apparently not of terrigenous origin, but genetically belongs to the epimatrix (Dickinson, 1970). The epimatrix is predominantly composed of quartz, chlorite, and sericite. Cement is largely quartz, and some illite and feldspars may be present.

The shales are of similar composition as the sandstones, although no lithic grains could be found within them. X-ray diffraction indicates that the coarse-fraction is composed of quartz, muscovite, plagioclase, microcline, chlorite, and calcite. In the clay-size fraction illite and chlorite are dominant.

Shales occur immediately at the base of the circular bioherms, and at their lateral extremities. The contact between the limestones and shales is sharp, and the boundary is indicated by a thin limonitic coating or film. At this marginal boundary are inclusions of quartz and feldspars, cemented and even partially replaced by calcite.

ENVIRONMENTAL INTERPRETATIONS

Observed features, noted above, of the clastic sedimentary rocks surrounding the coral bioherms indicate that they were deposited in the transitional zone between the shoreline and the shelf (Reineck and Singh, 1975). A prime characteristic for deposition within this transitional zone is the presence of shales interbedded with thin sandy layers. The black shale that occurs at the base of the coral bioherms, and in the area immediately surrounding the bioherms, was deposited in an environment of low water energy. However, the presence of some distinctive interbedded sandstones show characteristics attributed to occasional storm deposited layers (Reineck and Singh, 1975).

A schematic interpretation of the depositional setting of the circular, quiet water coral bioherms, and the adjoining areas, is shown in Figure 6. Field observations tend to suggest that the source of the clastic terrigenous material was situated to the south or southwest of the studied area. Apparently, the clastic material was deposited by continuous currents acting on the fore-slope of the barrier-reef area (Fig. 6). During storms, agitated waters were able to move and sort newly deposited material and carry it into the subsiding transitional zone. During certain intervals, corals lived and developed on the sea bottom and were able to produce small patch-reefs and coral

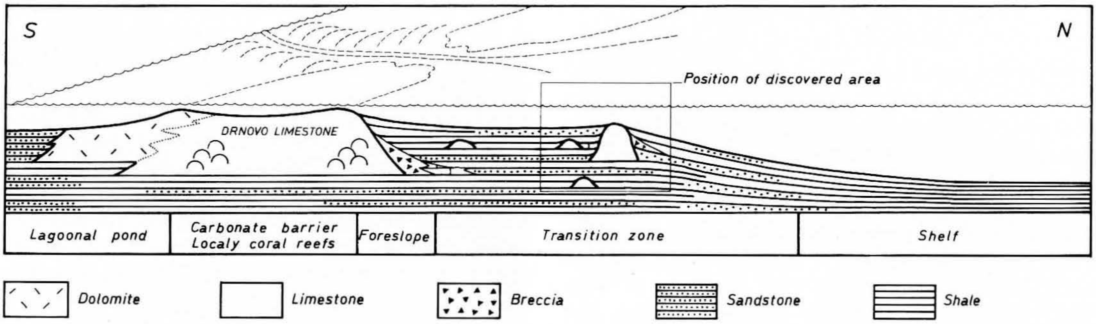

FIG. 6.—Schematic diagram of the interpretation of sedimentary environments in western Slovenia during Upper Triassic (cordevolian) time.

"meadows." During favorable time periods they coalesced and grew into numerous small bioherms and reef-knolls. Most of the smaller coral growths were short-lived and only attained a diameter of a few square meters, and a height of only a few meters. Many of these structures were quickly killed-off by influxes of mud. In areas where clastics were diverted conditions for growth of larger bioherms was satisfactory. Within a uniformly subsiding area, with ideal conditions, some coral bioherms were able to attain a growth height of up to 140 meters. But it should be kept in mind, that this height dimension is the final product of total coral bioherm growth. At any one time the coral bioherms were probably low-relief structures only slightly higher than the surrounding substrate. As a result there is an absence of biotic differentiation, on a vertical scale, of varied coral biohermal communities. The equilibrium established between coral reef structures and the surrounding sediments is indicated by the contacts of the biohermal cores with the surrounding sediments. However, there does appear to have been time intervals in the growth history of these bioherms when subsidence slowed down and the uppermost portions of the coral structures were exposed to more agitated wave and current conditions. It is at these times when the material for the marginal breccias was derived, and incorporated within the bioherms. The growth of the various intervals of bioherms appears to have ceased when sudden and spasmodic influxes of terrigenous mud engulfed the structures. As shown on the stratigraphic column (Fig. 3), this apparently happened a number of times.

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