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MEGAPOLYGONS IN LADINIAN LIMESTONES OF TRIASSIC OF SOUTHERN ALPS: EVIDENCE OF DEFORMATION BY PENECONTEMPORANEOUS DESICCATION AND CEMENTATION[1]

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ABSTRACT

Saucer-like structures (one to two m. in diameter when observed in cross-section) of dolomitized laminar fenestral intramicrite are interbedded with dense burrowed Ladinian micrite of the Esino Formation. This Triassic sedimentary sequence is interpreted as representing a subtidal and intertidal carbonate mud flat capped by a supratidal flat of laminar fenestrate carbonate. This fenestral horizon shows evidence of early cementation, dolomitization, fracturing, upward folding and some overthrusting. A later subtidal carbonate mud fills the fractures and covers them. Similar deformation of bedding occurs in the Holocene subtidal intertidal, and supratidal sediments of the Persian Gulf off Qatar and Abu Dhabi, and in the supratidal sediments of Shark Bay, West Australia. The Ladinian polygons of fenestrate sediment are interpreted to be the result of either desiccation contraction, or cementation expansion or more probably a combination of both.

INTRODUCTION

During research into the sedimentary facies relationships of the Ladinian and Carnian of the Triassic of the Bergamasc Alps in Italy (fig. 1) a series of quarries were visited in Val Seriana. One of these quarries cuts the upper part of the massive reef-like Ladinian Esino Formation (figs. 2, 3). Here rocks are being sliced by a wire system (Gay, 1883) for facing stone. Large polished surfaces over 100 m^2 have been produced and in some horizons of the limestones it was possible to recognize cross-sections of large saucer-like structures. These structures form the subject of this paper. Petrographic terminology after Folk 1959.

DESCRIPTION

The saucer-like structures occur in the uppermost part of laminar fenestral horizons of intramicrite which cap fossiliferous micrite. This sequence is repeated vertically and ranges from 50 to 200 cm in thickness. On the eastern face of the quarry where the best examples of the saucer structures can be seen, the following sequence (fig. 4) occurs.

1.) *Burrowed recrystallized fossiliferous micrite:* this bed is 100 cm thick and lies conformably on the laminated fenestral layer which caps the underlying cycle. Megascopically the rock is a dark-grey lime-mud cut by elongate tube-like structures (diameter 600–2000μ and length about 2.5 cm) interpreted as burrows. In the lower 30 cm of this lithology these burrows are sparsely distributed (one per 10cm^2) and some gastropod tests (0.5 to 4 cm in diameter) occur. Upwards the density of burrows increases (3–4 per 10 cm^2). A well spaced network of fractures thought to be late diagenetic (fig. 4) occurs near the base of this bed. In thin section the lime-mud can be seen to be formed by microspar (6–12μ diameter) with a mode of 10μ. The tubular burrows are filled by randomly oriented crystals of sparry calcite which are 10–50μ in diameter at the edge of the burrows and 100–300μ in the center. The contact between the spar and surrounding micrite is sharp. In addition to the burrows there are also scattered irregular patches (120–240μ diameter) of recrystallized calcite with a grain diameter of 30–50μ.

The presence in these beds of sparse fossils, apparently unsorted by waves or currents, the closely spaced burrowing, the dark color evidencing the presence of nonoxidized organic matter, the lack of cross-bedding, and the position of the bed at the base of the sequence all suggest that these sediments accumulated in a protected shallow subtidal lagoon. Recent analogues of this lithology occur in parts of Florida Bay, the Bahama banks west of Andros (Roehl, 1967, Shinn *et al.*, 1969), the inner parts of the eastern lagoons of Abu Dhabi (Evans *et al.*, 1964) and western Qatar Persian Gulf. (Illing *et al.*, 1965).

The petrographic fabric of this lithology sug-

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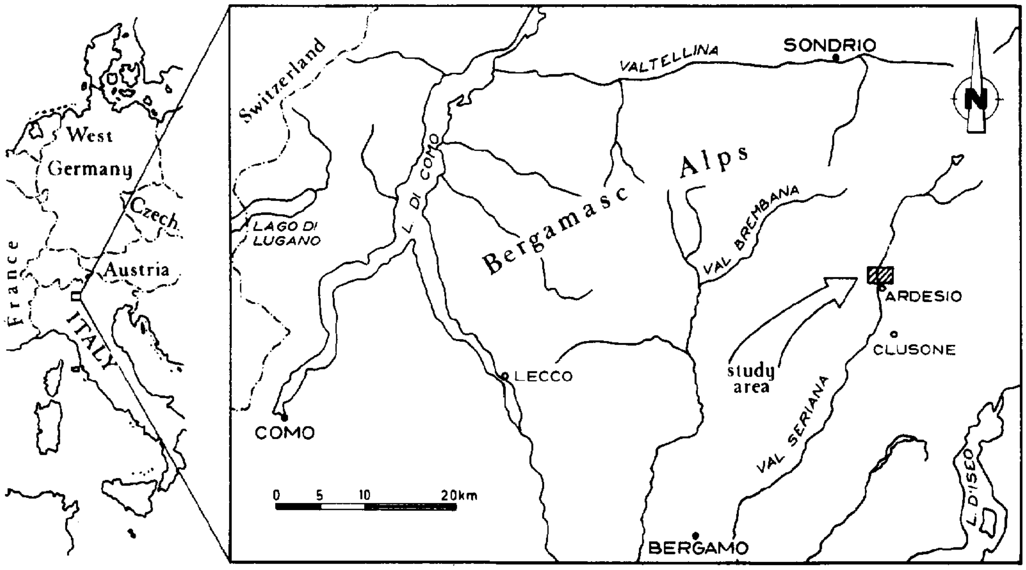


FIG. 1.—Location of the general study area.

gests that its diagenesis is connected in some way with the sequence. In particular the size of the microspar diminishes gradationally upwards into the upper litholgies. Perhaps the mechanism which produces an increase in crystal size is penecontemporaneous and similar to that described by Taylor and Illing (1969) for beach rocks off Qatar. However no evidence of the comparative age of this process was found and it may be a late diagenesis related to the original sediment fabric.

2.) *Sparsely recrystallized burrowed intramicrite:* megascopically this rock is a light-grey dense lime-mud 60 cm thick. Irregularly dispersed through the rock are gastropods and oncolites. Infrequent elongate tubes, interpreted as burrows, cross the rock. In thin section the rock is composed of intraclasts (180μ modal diameter) and foraminifera (180μ modal diameter), in a matrix of microspar (4μ to 8μ diameter; mode 7μ). The intraclasts are generally recrystallized and sometimes have the appearance of patches of spar cement. In the upper 10 cm of the bed, elongate fenestrae are present (maximum length 4–6 mm, maximum width 2–2.5 mm). The fenestrae are filled by micrite (between 500–800μ thick) overlain by randomly oriented calcite spar (150–200μ in diameter).

This rock is interpreted as having been deposited in an intertidal environment since it directly underlies dolomitized laminar fenestral beds which are known to be supratidal/upper intertidal (Shinn, 1968). This interpretation is consistent with the presence of well-sorted small intraclasts, some pisolites, fossils and burrows. Again similar analogues occur in the Holocene of the Bahamas (Roehl, 1967; Shinn *et al.*, 1969), Abu Dhabi (Evans *et al.*, 1964) and Qatar (Illing *et al.*, 1965).

3.) *Fenestral dolomitized intramicrite:* this is the horizon in which the saucer-like structures occur and is approximately 40 cm thick. In outcrop the rock is composed of fenestrated dolomitized intramicrite. The intraclasts increase in size upwards and the uppermost dolomitized material consists of clasts of broken fenestral material, coated grains, pisolites and intraclasts of micrite. In thin section, the lower part of the fenestral sediment is composed of rounded clasts of fine grained dolomite (4μ–8μ in diameter) ranging in size from 90μ to 450μ. Some are well sorted and bimodal, with modes of 150μ and 450μ. There is a distinct gradation from intraclasts with clear boundaries to intraclasts which merge with the micrite. The walls of the fenestrae and the surfaces of adjacent intraclasts show signs of solution and are darkened. The fensetrae are filled by equant calcite spar (150–500μ diameter). The source of some of the intraclasts is thought to be the underlying burrowed micrite. Other intraclasts are merely reworked fenestral crusts. The pisolites may be blue-green algal-coated grains probably derived from the adjacent low intertidal or subtidal environments.

The environment of deposition of the dolomi-

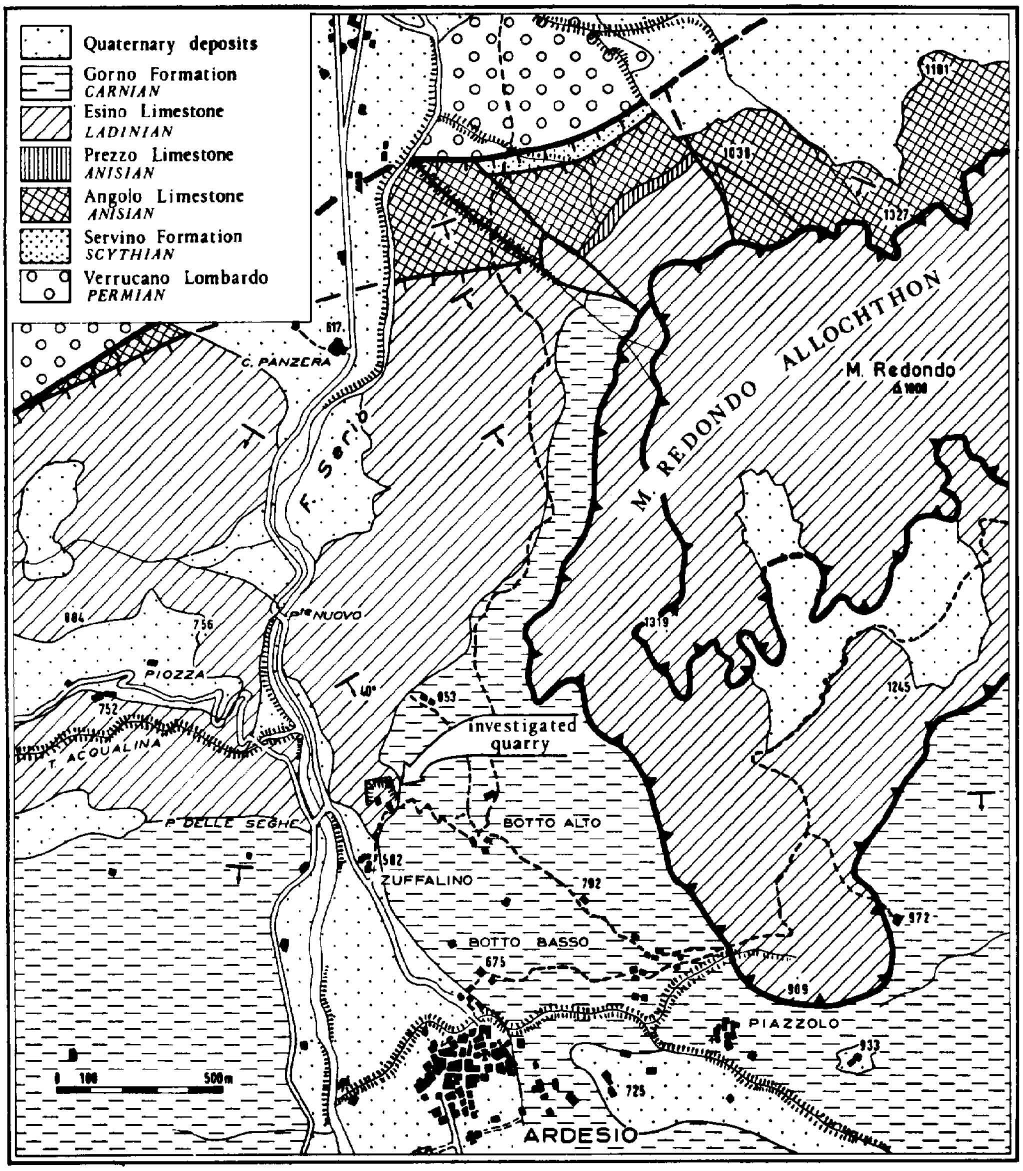


FIG. 2.—Location of the Val Seriana quarry investigated and geological sketch map of the surrounding area.

tized fenestral intramicrite is thought to have been a supratidal or upper intertidal flat overlying an intertidal mudflat (the burrowed micrite). This was subjected to early beachrock cementation by micrite in conjunction with dolomitization. This process is similar to that described for the Holocene crusts west of Andros Island Bahamas (Shinn *et al.*, 1965), the algal mat crusts of Shark Bay Australia (Davies, 1967 and 1970) and some of the surface beach rock of Qatar (Taylor and Illing, 1969). It is thought the fenestrae represent early desiccation and gas movement in supratidal sediment before cementation (Shinn, 1968; Kendall, 1969). The cavities are filled by later sediment and show evidence of minor solution. This solution was probably caused by intermitten passage of marine floodwaters or rainwater before the deposition of the overlying sediment.

At regular horizontal intervals of 1.5 to 2 m,

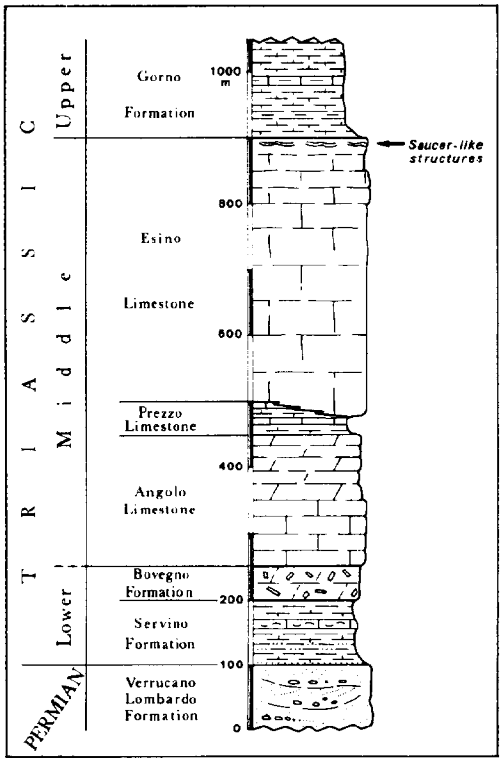


FIG. 3.—Generalized Triassic stratigraphy in upper Val Seriana. Modified from Asserto & Casati (1965).

these beds are broken and gently bent upwards (fig. 5). The lower laminae of those beds are only slightly curved up to form low narrow folds while the upper laminae, which are thicker, are disturbed more intensely to form angles up to 35° with the general bedding surface, with some laminae actually overriding one another (figs. 4 and 5). This upper surface, particularly the more elevated portions, shows local evidence of slight erosion and reworking. The differential bending and cracking of the fenestral horizon forms large cavities in the "tepee" like structures. The lower part of these cavities is filled by a 2–3 cm thick layer of thinly laminated micrite while the upper part is filled with the fine gastropod micrite which forms the base of the overlying bed and represents the initiation of a new cycle (fig. 6).

DISCUSSION

The different angles of the bent laminae in the saucer-like structures and the presence of overriding and of sheet cracks separating sets of laminae suggest that differential movement took place between the laminae. This movement occurred before the burial of the fenestral beds by the overlying sediments. Evidence for this is that the disturbed beds have been slightly eroded and that the lower parts of the voids between the fenestral beds contain geopetal micrite, quite unlike that of the immediately overlying carbonate which completes the filling of the cavities and begins the next cycle of sedimentation.

The regular spacing of the saucer-like structures suggests that a uniform agent was acting during their formation. From a theoretical standpoint the following processes can be invoked for these structures. Either the upper surface of the disturbed bed underwent reduction in area with respect to the lower part, or the lower part of the bed or even the whole bed underwent expansion.

The first process would be expected in supratidal and high intertidal environments. Here the surface sediments are exposed above sea water for long periods. Desiccation reduces the surface area of the most exposed upper sediment, with the production of concave polygons. This form of polygon is not uncommon in many Holocene upper intertidal and supratidal environments. In the Khor al Bazam of the southern Persian Gulf, Kendall and Skipwith (1968) observed saucer-like desiccation polygons in algal mats. These ranged in diameter from a few centimeters to at least 1.5 m. and the size seemed related to the thickness of the desiccated bed. Similarly-desiccated mud and fine sediment may be cracked and form upward curved saucers (Kindle, 1917).

The other mechanism for saucer formation requires the expansion of part, or of the whole disrupted layer. This expansion can be produced by crystal formation at or near the sediment air interface and polygonal saucers would be expected to form with buckled boundaries. If the sediment *and/or* crystal complex is plastic, no breakage occurs. Examples of expansion by crystal growth include the development of polygons of anhydrite just below the surface of supratidal sediments in the Southwest Persian Gulf (Kendall and Skipwith, 1969a). This anhydrite shows signs of plastic folding and bending with local overthrusts and diapiric structures. If the horizon is less plastic, as for example in a surface crust of halite, expansion causes disruption with heaving and thrusting. Hunt *et al.* (1966) report modern saucers of halite 6–7 m in diameter from Death Valley, USA. They interpreted these to be forming by desiccation contraction accompanied by upward and sideways growth of salt crystals. Similar halite polygons have been illustrated from the suprati-

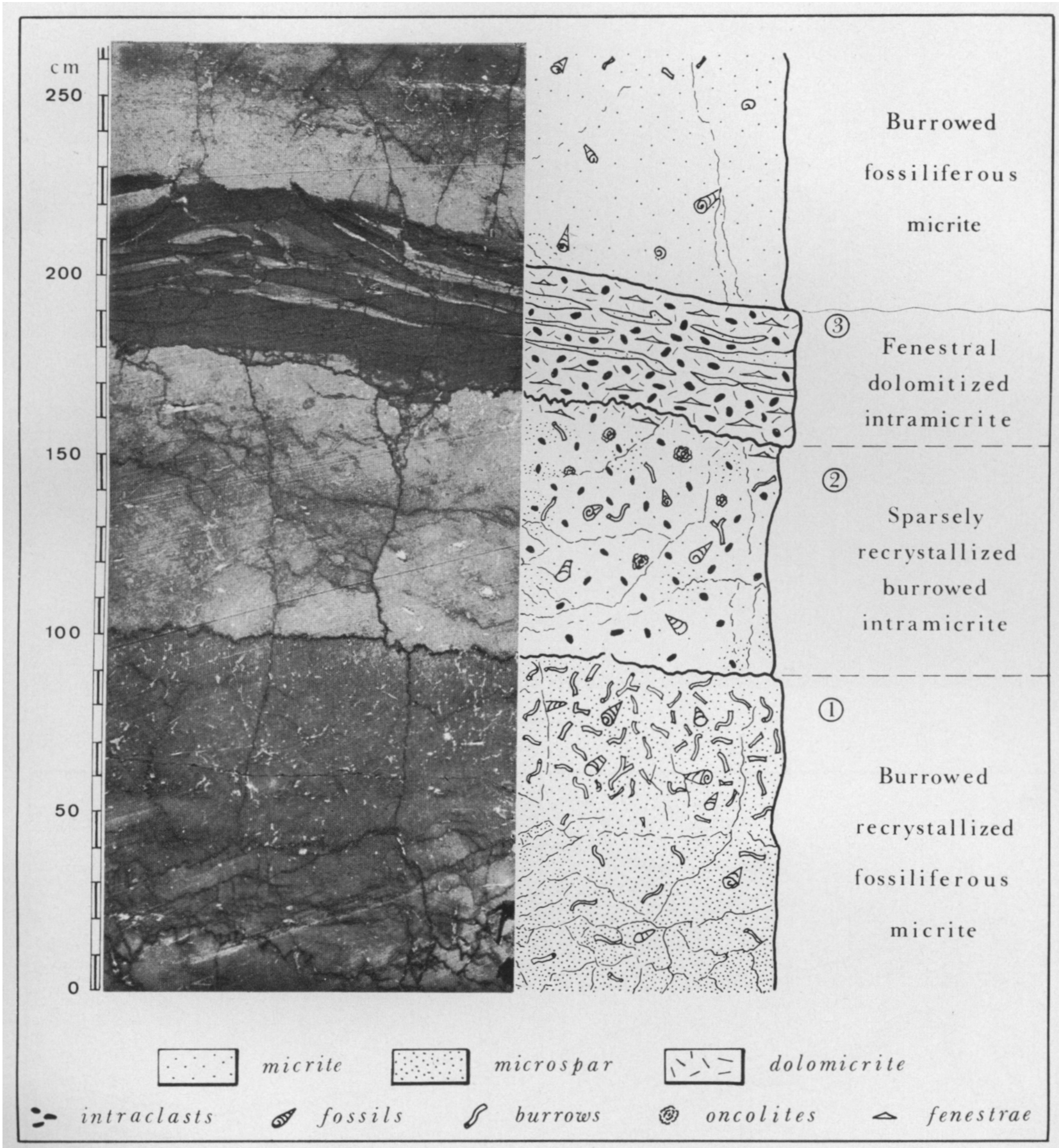
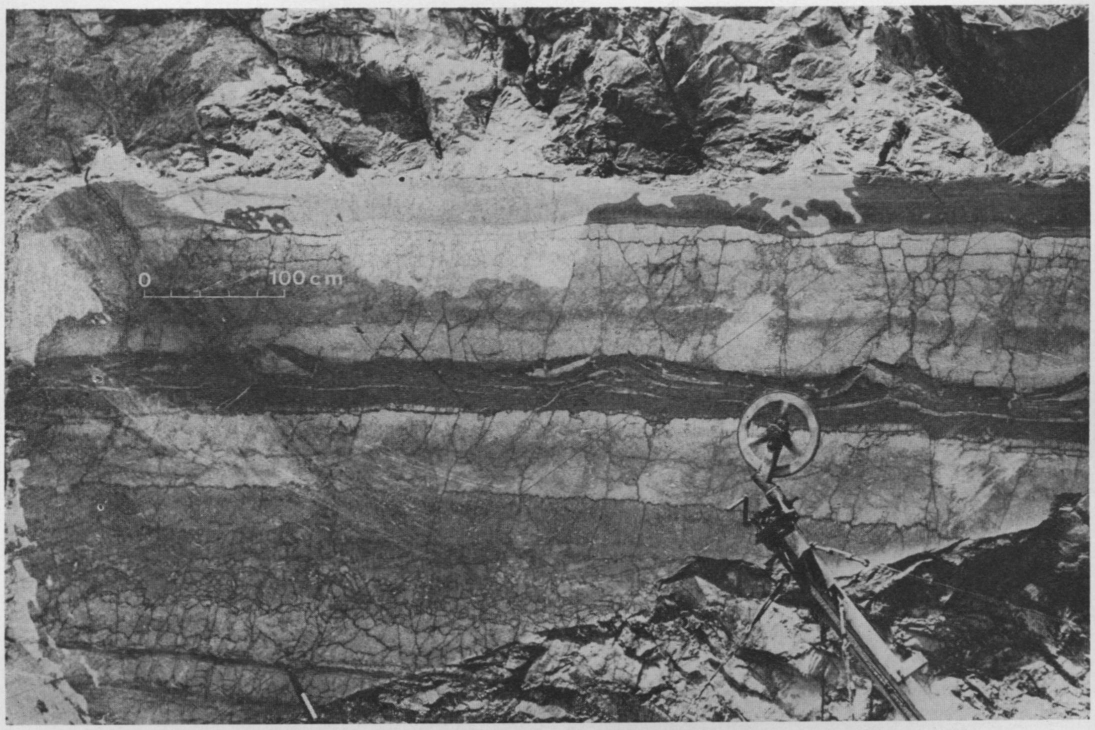


FIG. 4.—The most common cyclic sequence of the Val Seriana quarry. The saucer-like structures occur in the fenestral dolomitized intramicrites. Note overriding of the buckled and cracked fenestral horizon.

dal salt flats of Abu Dhabi, Persian Gulf (Kendall and Skipwith, 1969a; Evans *et al.,* 1969). Until recently it has been less commonly known that expansion can occur in carbonate sediments. Large polygons several tens of meters in diameter have been observed in subtidal waters off Abu Dhabi (fig. 7) (Kendall and Skipwith, 1969b). Shinn (1969) inferred that these polygons are forming today by expansion caused by the force of carbonate crystallization. Individual layers are growing and over-riding one another.

Carbonate polygonal saucers can be formed also by the combined action of both desiccation contraction and crystal expansion. Desiccation initiates the polygonal form and crystal growth continues this form. If expansion dominates, then over-riding takes place. This overriding has been reported by Davies (1967 and 1970) to be occurring in the high intertidal and supra-


0
100cm

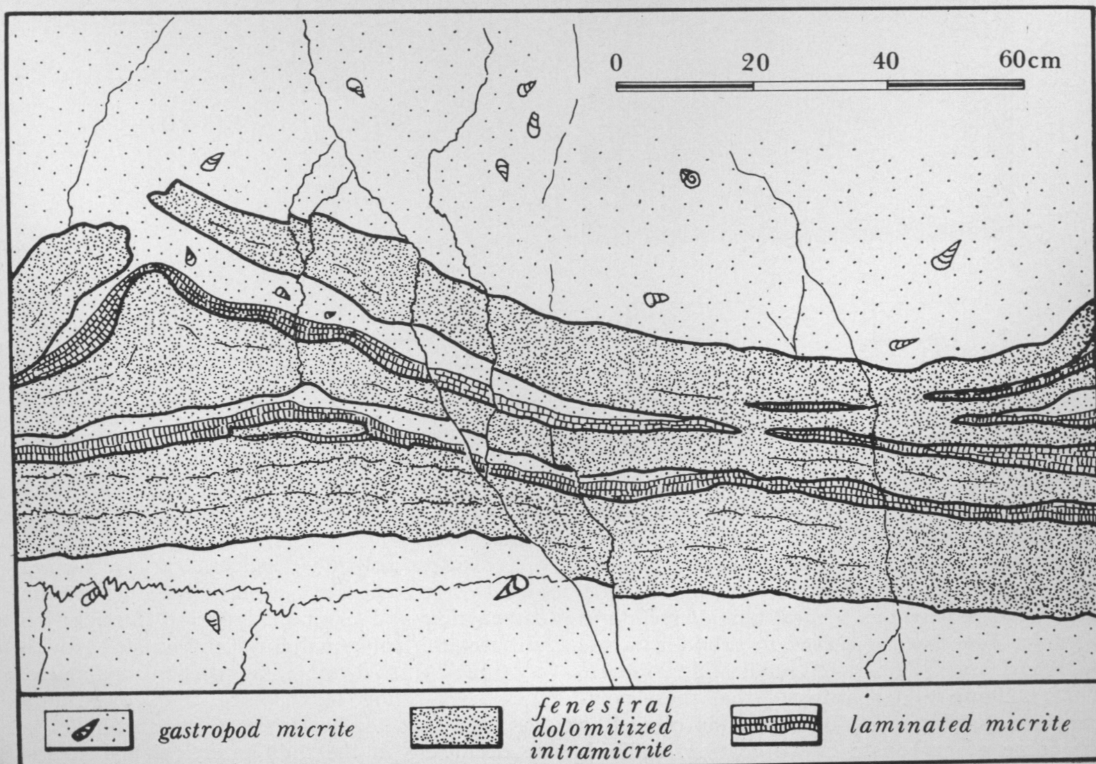

0
20
40
60cm
gastropod micrite
fenestral dolomitized intramicrite
laminated micrite

FIG. 5.—Photograph of the eastern face of the Val Seriana quarry showing large saucer-like structures. The saucers (diameter 1.5–2 m.) formed by the bending of a 40 cm thick fenestral intramicrite bed.

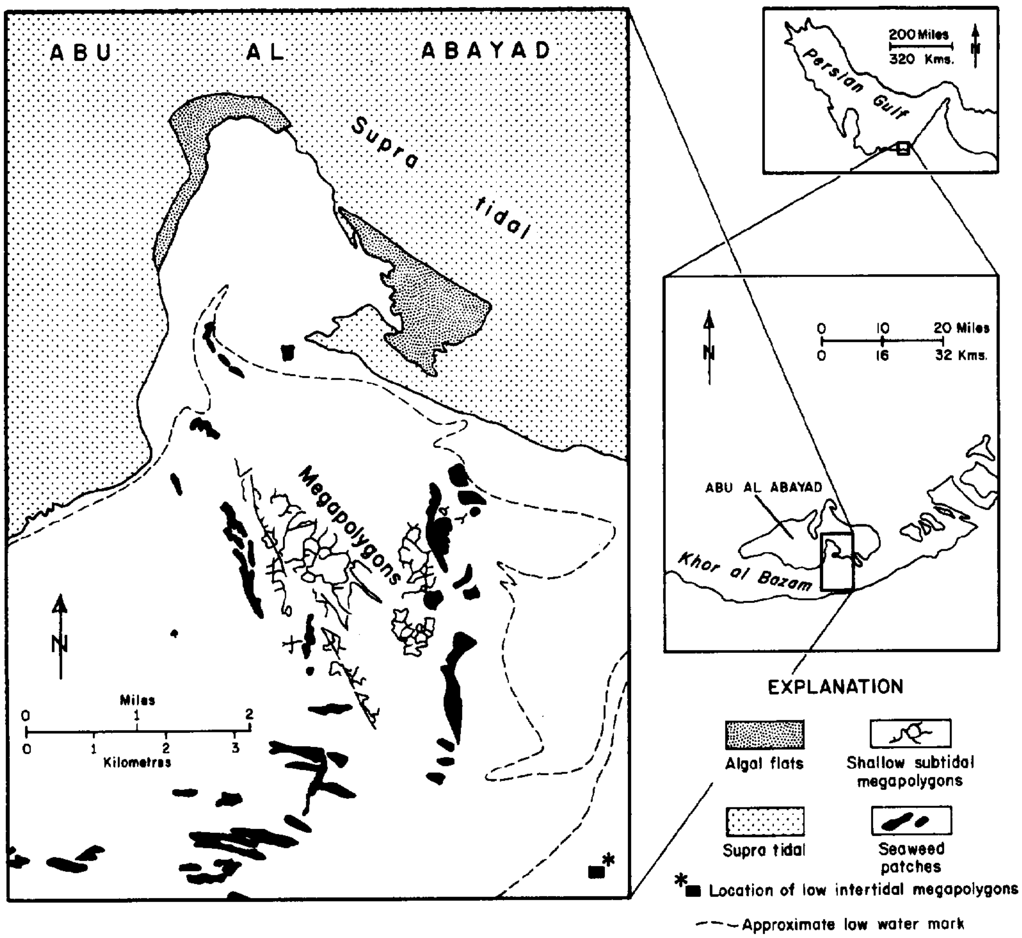


FIG. 7.—Location of shallow subtidal and low intertidal megapolygons in the Khor al Bazam, southwest Persian Gulf. Modified from Kendall and Skipwith 1969b.

FIG. 6.—Drawing from a photograph showing part of a large "tepee"-like structure formed by the differential bending and cracking of the fenestral horizon. The lower part of those cavities is filled by a 2–3 cm layer of laminated micrite while the upper part is filled with fine gastropod micrite.

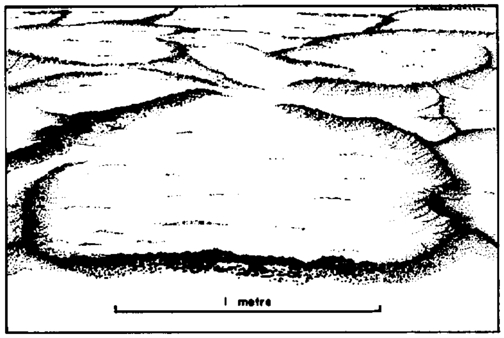


FIG. 8.—Drawing from a photograph of low intertidal megapolygons from the Khor al Bazam. Note the raised cemented edges protruding through a surface of unconsolidated tidal flat sands.

tidal of the carbonate province of Shark Bay. Here beach-rock cementation of the surface sediments covers several hundred square kilometers and megapolygons up to one metre in diameter and three to five cm thick occur with overriding edges of a few centimeters. Larger polygons contorted at their edges and up to 1.5 meters in diameter (fig. 8) occur in the intertidal sediments just seawards of the algal flats of the Khor al Bazam. These polygons are inferred to be forming by process similar to those of Shark Bay.

All the processes described could have been responsible for the formation of the Val Seriana saucer-like structures. Only a study of the three dimensional shape of the saucers might indicate which process acted, but none of the disturbed sediment is presently exposed in plain view. However the cross-sections show that deformation is restricted to desiccated supratidal fenestral beds and these have been folded, fractured, and locally overriden. This does suggest expansion, even if it is on a small scale. Thus the Val Seriana saucer-like structures are considered to be megapolygons analogous in origin to similar structures in the upper intertidal and supratidal of Shark Bay and the Khor al Bazam. They are thought to have been formed by the combined action of desiccation and some crystal expansion.

The Val Seriana saucers are an initial step in penecontemporaneous carbonate deformation. The next step can be seen in similar but "Texas-sized" polygonal saucers, known as tepees, in the Permian of the Guadalupe Mountains. Here the saucers in addition to the combined action of desiccation and cementation expansion are thought by Kendall (1969) to be deformed by precipitation of fibrous carbonate cement along bedding and fracture surfaces.

CONCLUSIONS

In summary the results of the studies in Val Seriana suggests the following conclusions:

1) Horizons of dolomitized fenestral intramicrite (40 cm thick) have regularly spaced disruptions (every 1 to 2 m) in which the bedding is fractured, bent upwards and overriden.

2) The dolomitized fenestral intramicrite is thought to have formed in a supratidal to high intertidal environment.

3) The interbedded burrowed micrites are interpreted to be from an intertidal to subtidal environment adjacent to the fenestral intramicrite.

4) The environmental setting is believed to be a shallow bay or lagoon protected from waves, similar to the bays of southwest Shark Bay, west of Andros and northeast Abu Dhabi.

5) The disruptions were penecontemporaneous with the cementation and dolomitization of the fenestrate intramicrite.

6) The disruptions are thought to be cross-sections of saucer-like megapolygons formed either by the action of penecontemporaneous desiccation or by expansion due to force of crystallization or most probably by a combination of both.

The basis for these conclusions is comparison with Holocene sediments showing similar sedimentary relationships and textures.

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