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Origin of the lithographic limestones

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Megascopically dense, homogeneous, even-bedded limestones are termed "lithographic limestones", no matter if they have been employed in graphic art or not. A characteristic of these limestones is their conchoidal fracture. There are almost no rock-forming fossil fragments, and inorganic detritus plays no part in the formation of the rocks. They consist of microscopic and sub-microscopic calcite crystals firmly aggregated. As no rock-building organisms have been traced in the limestones, precipitation of the calcium carbonate has been regarded as inorganic or ascribed to bacteria. The environment in which the lithographic limestones were formed — shallow, probably lagoon-like basins — has been ideal for precipitation, whether it occurred inorganically or by the agency of bacteria.

It has proved difficult in the study of recent calcareous mud to establish any large scale inorganic precipitation of calcium carbonate. On the other hand, it is known that enormous quantities of bacteria are present in shallow sedimentation areas with fine calcareous mud. There is no doubt that the bacteria have contributed to the formation of this mud. The process has been described and discussed for decades by a number of scientists and is now so generally known that it will not be dealt with here.[1]

One may ask how the bacterial flora could develop to such an extent that it gave rise to thick and extensive mud deposits and limestones. The question has generally been passed over or dismissed with the explanation that the sedimentation took place in quiet, shallow, and warm water where

[1] Experimental investigations into the precipitation of calcium carbonate by bacteria have also been carried out, e. g. by W. O. KALINKO (according to report in Centralblatt für Mineralogie 1953, II, 523).

the bacteria thrived. It has, however, been found that the concentration of bacteria is particularly high where the mud contains organic particles (as in mangrove swamps). It is an inescapable fact that the calcium carbonate-precipitating bacteria, just as much as others, have needed nutrient substances. To give rise to large quantities of mud of the kind which forms the lithographic limestones the bacteria must have flourished to an unprecedented extent, which in turn must have called for large quantities of nutrient substances of a suitable nature. So far it has not been possible to find any trace of these substances in the lithographic limestones or in the mud deposits. A ready explanation would be that the nutrient substances were completely decomposed by the bacteria and that they did not contain any resistant parts. However, the question of their character is still open.

In studying lithographic limestones and other calcareous rocks which in one respect or another show affinity with them, the author has observed conditions which may well contribute to an understanding of the causes of the flourishing of bacterial flora and the formation of lithographic limestones. These conditions will be clarified by means of a short report on some of the rocks investigated.

The Jurassic lithographic limestone of Solnhofen

Samples from beds of varying thickness were examined. In certain cases the rock consists of evenly distributed calcite grains, 1—3 μ, and scattered larger calcite crystals, 10—30 μ, (fig. 1 a, photo 1784). In other instances the limestone is microscopically heterogeneous and clotted (flocculent). Diffusely bordered, cryptocrystalline, light-absorbing portions lie in a distinctly crystalline, brighter calcite aggregate (fig. 1 b, photo 1772). This clotted form of the Solnhofen limestone is of particular interest because a similar texture is typical of several other lithographic limestones. It gives a clue to the understanding of their formation.

Lithographic limestones in the Jurassic of England

In various places the Jurassic of England contains lithographic limestones with the same types of texture as those from Solnhofen mentioned above. Three forms will be described here, one from the region of Bath and two from the Isle of Portland.

Samples of lithographic limestones from the White Lias in the region of Bath cannot be distinguished megascopically from the Solnhofen lime-

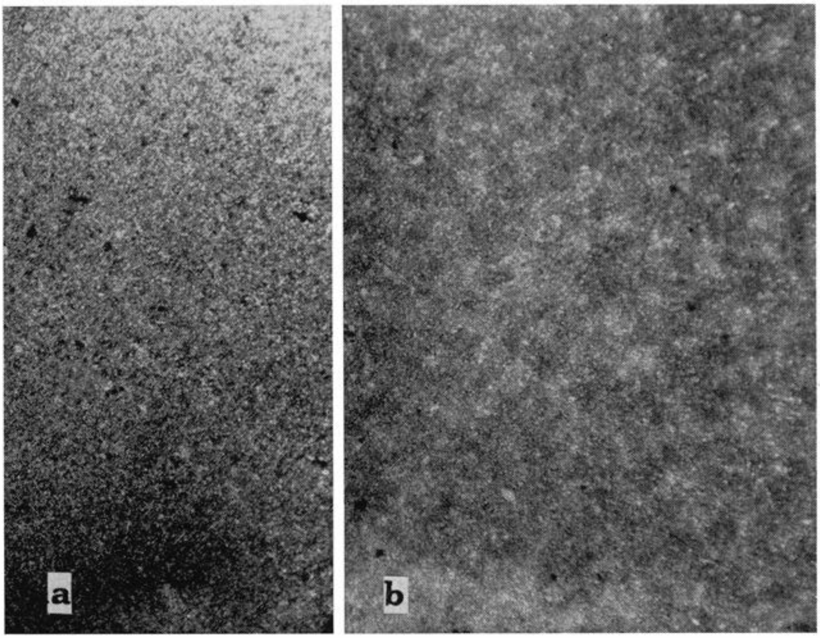

Fig. 1. Lithographic limestone. Upper Jurassic (Portlandian). Solnhofen. — *a*. Even-grained form. Prep. 7784, photo 1784. *b*. Clotted form. Prep. 7871, photo 1772. — 90 ×.

stone. The denseness, the conchoidal fracture, the faint yellow colour, and the thin beds with even bedding surfaces are characteristic of both limestones. Microscopically the Bath rock resembles the even-grained types from Solnhofen (fig. 1 a). It has, however, on an average somewhat coarser calcite grains (2—10 μ). To what extent flocculent types, too, are found in the series of strata at Bath is not known to the author.

On the Isle of Portland, in the coastal section west of Weston, there are beds of lithographic limestone, formed in very shallow water. Two types of the limestone will be illustrated.

a) Megascopically dense, faint yellow limestone, hard and with conchoidal fracture. Microscopically it is strongly clotted with dusty, diffuse, light-absorbing flocks or nodules in a distinctly crystalline, more transparent calcite aggregate (fig. 2, photo 1773). The rock has the same texture (size of crystals and flocks) as the flocculent form of the Solnhofen limestone, and it must have been formed in the same way.

b) An adjacent bed is somewhat brighter and more porous. The fracture is less pronouncedly chonchoidal and the fracture surface duller than in

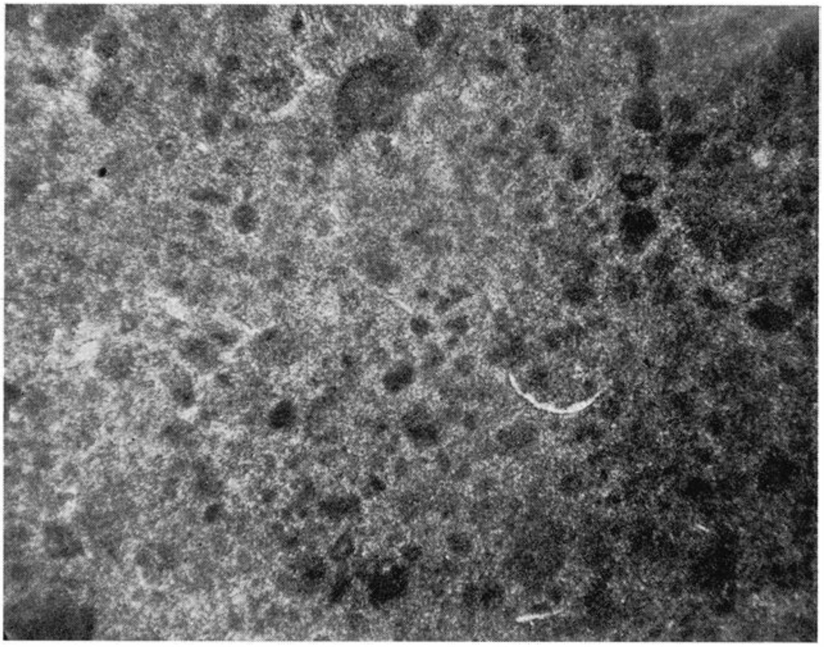

Fig. 2. Lithographic limestone. Upper Jurassic (Upper Portland). Isle of Portland, Dorset, England. Prep. 8305, photo 1773. – 90 ×.

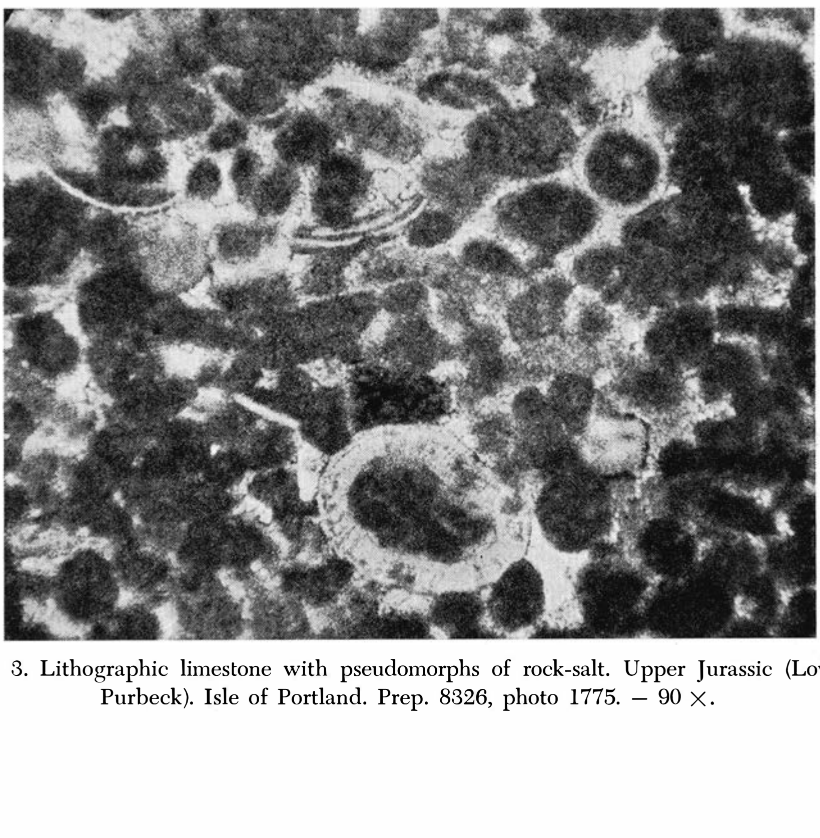

Fig. 3. Lithographic limestone with pseudomorphs of rock-salt. Upper Jurassic (Lower Purbeck). Isle of Portland. Prep. 8326, photo 1775. – 90 ×.

type *a*. Microscopically it exhibits the same textural features: cryptocrystalline, light-absorbing, diffusely bordered flocks (nodules) in a distinctly crystalline, bright calcite matrix (fig. 3, photo 1775). The flocks are considerably larger in type *b* than in type *a*, but they are of exactly the same nature. — In the upper bedding surface of the coarsely flocculent bed cubic salt-pseudomorphs are visible. The sedimentation must have taken place in the littoral zone.

Lithographic limestones in the Silurian of Gotland

In the lower part of the Silurian of Gotland, in the uppermost part of the Högklint group to be exact, there is found in places a megascopically dense, thin-bedded or laminated, partly shaly, faint yellow limestone with even bedding surfaces and conchoidal fracture. Together with this litographic limestone the same part of the group contains other similar, but less dense, fine-grained forms. The various forms grade into one another, and they must have been deposited under similar conditions. Two types, *c* and *d*, corresponding from a textural point of view most nearly to those from the Isle of Portland mentioned above, will be described.

c) Thin bed, rock megascopically dense and with conchoidal fracture, hard and resonant. Microscopically finely flocculent with diffusely bordered cryptocrystalline, strongly light-absorbing flocks (nodules) in a bright, microcrystalline calcite matrix (fig. 4, photo 1779). The only petrographic difference between this rock and the Portland type *a* mentioned above is that the matrix in the Silurian form is more strongly recrystallized than in the Jurassic form.

d) Light brownish-yellow bed divided into layers of 8—10 mm. Rock megascopically dense or extremely fine-grained. Fracture faces dull, not markedly conchoidal. Microscopically flocculent with diffuse, cryptocrystalline, light-absorbing flocks (nodules) in bright, well crystallized calcite matrix (fig. 5, photo 1780). In certain cases the flocks have a core of fossil fragments, in others they have been partly recrystallized, especially in the centre. — Despite stronger recrystallization and larger flocks this Silurian limestone is of the same nature as the above-mentioned Liassic type *b*.

The two limestones mentioned from Gotland appear in a series of strata of a pronounced shallow-water nature.

It is exposed in several places in Northern Gotland. Conglomerates, cross bedding, and an abundance of calcareous algae characterize certain parts of the series in some areas. In other places there appear laminated,

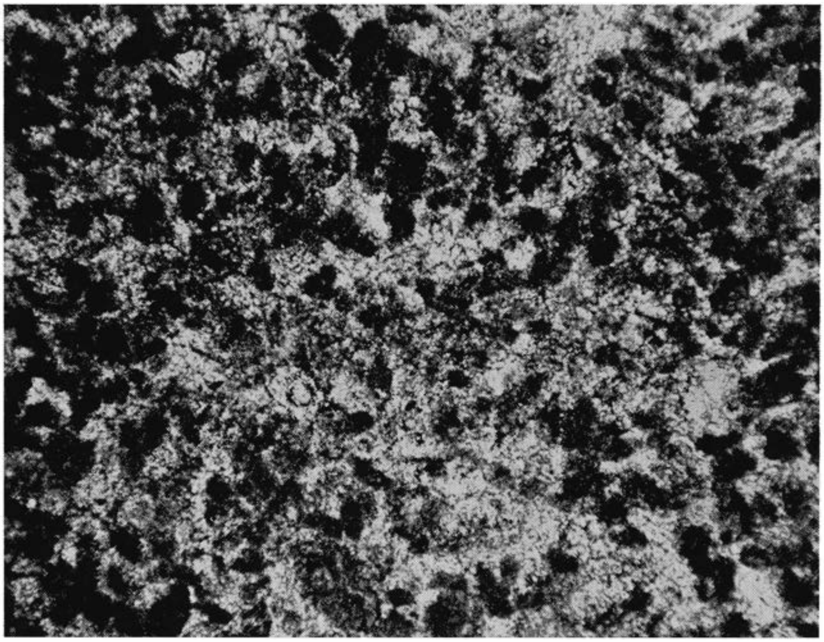

Fig. 4. Lithographic limestone. Silurian (Wenlockian). Visby, Gotland, Sweden. Prep. 6476, photo 1779. — 90 ×.

Fig. 5. Dense limestone with diffuse nodules. Silurian (Wenlockian). Visby. Prep. 3393, photo 1780. — 90 ×.

slightly bituminous, dense limestones with the character of lagoonal deposits. (They include the *Pterygotus* beds at Visby.) Despite the differences just indicated all the sediments in the limited part of the sequence dealt with here must have been deposited under essentially uniform conditions: shallow water, high temperature, and small content of inorganic detritus and fossil fragments. An occasional and local agility of the water has been sufficient to produce the structural variations apparent in the rocks. The conditions of formation are displayed most clearly in certain respects in the rocks formed in turbulent water, and two of them will therefore be illustrated here: conglomeratic limestones with algal crust on the balls, and *Spongiostroma* limestone.

Conglomeratic limestone with algal crust on the balls.

Intraformational calcareous conglomerates of locally varying development appear in the upper part of the Högklint group at Visby as well as in Northern Gotland. The balls of the conglomerates usually have a core of fossil fragments and a crust of calcareous algae (see Hadding 1956, fig. 7 and 11). The crust is megascopically dense. Microscopically it is composed of sub-microscopic, strongly light-absorbing, flocculent calcite (fig. 6, photo 1783), intermingled irregularly with bright microcrystalline calcite. The diffuse flocks of the algal crust are of the same kinds as the flocks of the lithographic limestones discussed above. The only difference lies in the fact that the flocks are somewhat more compact in the crust than in the calcareous mudstones. Occasionally the crust, in addition to the flocculent calcareous algae, contains remains of filiform algae (fig. 7, photo 1782). The crust corresponds completely in texture and composition to the *Spongiostroma* balls which appear as rock-formers in the same series of strata.

Spongiostroma limestone, Gotland

In close connection with the above-mentioned Silurian limestones of Gotland are found beds with abundant *Spongiostroma* balls. These algal balls, which often have a diameter of 30—40 mm, are irregularly concentric or bulbiform in texture. The balls have grown on all sides since they have been rolled about by the surf. They are seldom homogeneous but composed of calcareous algae of different textures, e. g. *Sphaerocodium* and *Hedströmia.* The principal part always consists, however, of a flocculent mass identical to that found in lithographical limestones of flocculent texture (fig. 8, photo 1781). As this mass, both in *Spongiostroma*

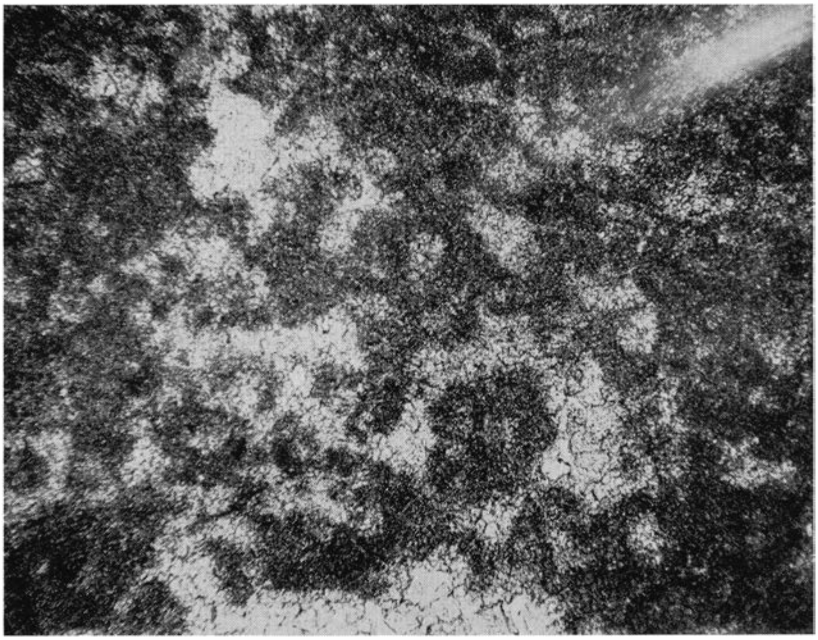

Fig. 6. Algal crust with clotted texture. Silurian (Wenlockian). Storugns, Gotland. Drilling core nr 26, depth 27.3 m. Photo 1783. – 90 ×.

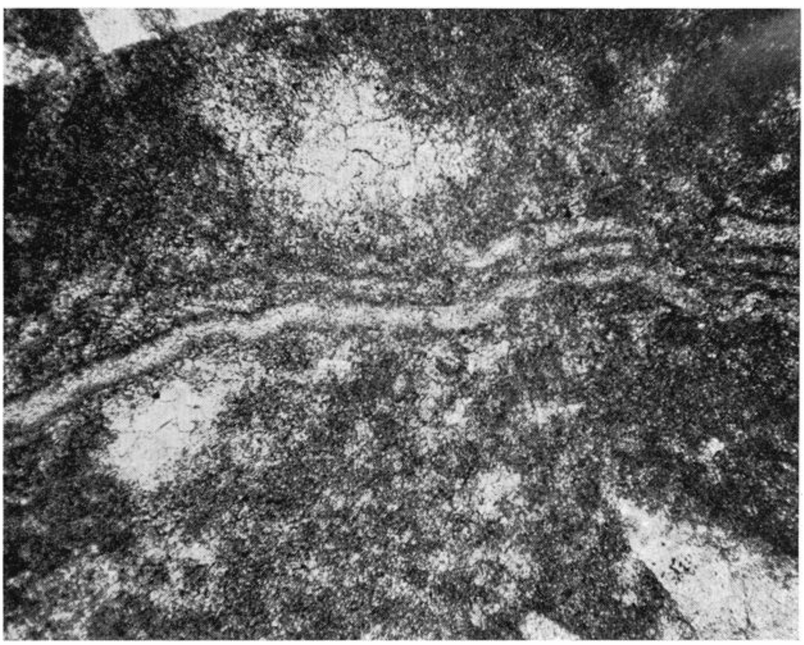

Fig. 7. Algal crust with clotted texture and algal threads. Silurian (Wenlockian). Visby, Gotland. Prep. 7753, photo 1782. – 90 ×.

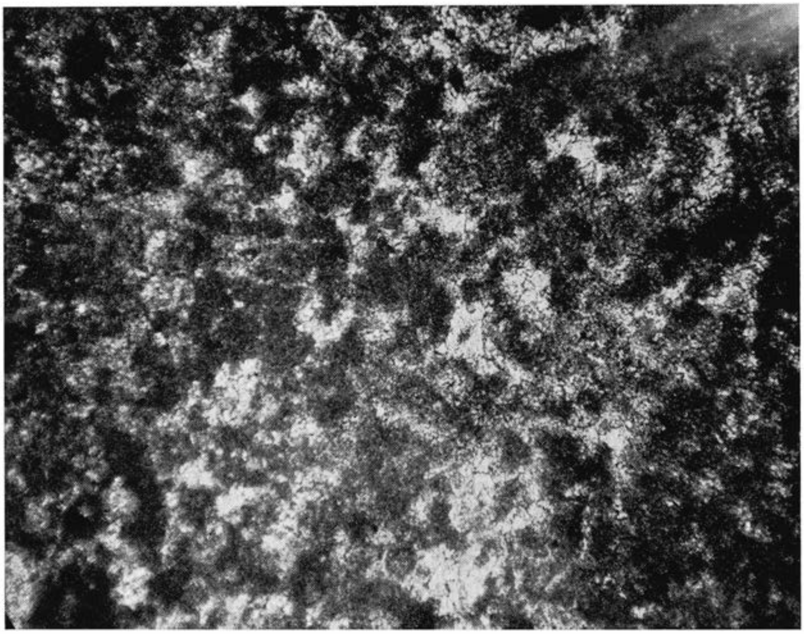

Fig. 8. *Spongiostroma*. Silurian (Wenlockian). Visby, Gotland.
Prep. 3345, photo 1781. — 90 ×.

and in the crust of the conglomeratic balls, is formed of calcareous algae, we have reason to draw the conclusion that *the flocculent portions of the lithographic limestones have also been formed by calcareous algae.*

Joint action of algae and bacteria

In the introduction it was mentioned that an enormous profusion of bacteria has been shown to exist in recent marin calcareous mud and that these bacteria, with good reason, are considered to have contributed to the precipitation of calcium carbonate. How the bacteria could have developed to such an extent was, however, a question which was unsolved, except as regards certain special environments (mangrove swamps). If we accept the author's interpretation of the texture of the lithographic limestones and the importance of algae for their genesis, a road would seem to have been opened for continued investigations towards the solution of the problem.

The dense, flocculent algal limestone which has been discussed here may either be composed of diffusely nodular portions or form more compact grumous masses. The diffuse, cryptocrystalline "nodules" are usually less than 40 μ in lithographic limestones and max. 200 μ in the less dense limestones mentioned here. The algae which have precipitated the calcium carbonate in the "nodules" have obviously formed a desirable source of nutrition for bacteria.[1]

One asks, what is the consequence of the bacteria's attack on the algae? If an intensive attack continues for a sufficiently long time, the alga (the organic substance) will be completely decomposed. The calcareous substance precipitated by the alga, the calcareous flock ("the nodule"), then crumbles unless it has already acquired a good cohesion and a certain size. If the bacteria develop in especially favourable circumstances, they can decompose the algae as quickly as the latter manage to form small flocks. The result is then that the algal flocks disappear. The rock acquires the even-grained, flock-free texture mentioned in the case of certain forms of lithographic limestones (fig. 1 a). From the proportion of flocks to matrix it is possible to deduce the relative importance of the bacteria for the formation of this particular rock.

Where the flocculent calcareous precipitate of algae form blurred masses, as in the algal crusts discussed above (fig. 6), bacteria would seem to have contributed to the final formation of the grumous texture. This texture has earlier been observed and interpreted in different ways, e. g. as a consequence of an unpervasive recrystallization (Cayeux 1935, 271; Pettijohn 1957, 412).

Some supplementary remarks

Limestones of much the same character as those discussed here are found in several places and within different geological systems. Here attention will be directed only to those limestones with pseudo-oolitic and grumous texture (Calcaire à la structure pseudoolithique et Calcaire à la structure grumeleuse) described by Cayeux (1935, 267–271), and to the report made by Wood (1941) on "algal dust" in certain Carboniferous limestones.

Elongated ellipsoidal fine-grained calcareous aggregates have been observed in calcareous mud and limestones. They have generally been looked upon as pellets of faecal origin. This interpretation has not, how-

[1] Pia asserts (1934, 55) "dass die Tätigkeit der Bakterien sich hauptsächlich im Schlamm und in den tiefsten Wasserschichten unmittelbar über ihm abspielt, wo die Nahrung für sie viel reichlicher vorhanden ist. Allerdings darf das Wasser nicht tief sein." — In the samples investigated by the author there is nothing to contradict the accuracy of Pia's view.

ever, been wholly accepted. Thorp (1935, 63) comments that "the problem is not yet sufficiently clarified to include all soft bodies which bear close resemblances". Probably algal nodules, too, of the kind discussed here have in some cases been called pellets. Ginsburg has shown (1954, 80) that "surface carbonate muds in Florida have as much as 50 % pellets, but, a few feet below the surface, compaction destroys their individuality, and they cannot be separated from the matrix".

In a notice concerning recent stromatolitic sediments from Florida Ginsburg (1955, 129) has pointed out the occurrence of sediment binding by algae. From other places, too, e. g. from lagoon deposits in the Persian Gulf, there is mention of calcareous mud preserved by the binding action of algae (Bramkamp and Powers 1955, 139). It is pointed out that under a thin aerobic surface layer the calcareous mud is sulfide-rich. It is therefore worthy of note that all the lithographic limestones discussed here lack iron sulfide.

Summary

Lithographic limestones often exhibit microscopical flocks or diffuse nodules of cryptocrystalline calcite in a microcrystalline calcite matrix. The same texture is found in certain bodies composed of algae, e. g. in *Spongiostroma* and in the algal crust of conglomerate balls. The flocks of lithographic limestones are interpreted by the author as having originated through the activity of algae. The algae have also served as nutrition for the bacteria, and they have been broken down by the latter to a greater or lesser extent. Concurrently the bacteria have precipitated the calcium carbonate forming the matrix of the rock, later on more or less recrystallized.

The lithographic limestones are lagoonal sediments, formed partly in the littoral zone. They are characterized by light colour, even bedding surfaces, conchoidal fracture, microcrystalline and cryptocrystalline texture, high $CaCO_3$ content (= extremely small content of inorganic detritus), poverty or complete lack of rock-forming megascopic fossils. They have been formed essentially by joint action of algae and bacteria in precipitation of calcium carbonate.

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