Mineralogy of Early Cambrian *Salterella rugosa* from East Greenland

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Specimens of *Salterella* from the Ella Ø Formation preferentially selected dolomite grains from a matrix mixture of calcite and dolomite, placing these inside a calcium carbonate conch. Quartz, feldspar, and hematite are also present in dolomite-rich layers within the specimens. Electron-probe examination confirms that the dolomite-rich layers are separated by thinner layers of calcite, implying that the organism emplaced a layer of grains and then cemented them before collecting grains for another layer.

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The Ella Ø Formation (upper Lower Cambrian) of East Greenland has yielded specimens of *Salterella,* identified by Poulsen (1932, p. 32) as *S. rugosa* Billings. Although for many years this genus was interpreted as a cephalopod, the presence of abundant internal laminae, rather than septa, demonstrates that this class assignment is not correct. Billings' type specimens have not been photographically illustrated but are under investigation (Yochelson, unpublished data), although comparison of the Greenland material with the type lot has not as yet been made, and specific identity of the Ella Island forms must remain open. Nevertheless, Poulsen's material is of considerable interest and provides new data on the life habits of *Salterella.* We thank S. Floris of the Geological Museum, Copenhagen, for allowing us access to the original thin sections and for supplying additional material for examination by the electron probe.

Filling of the *Salterella* conch

The genus *Salterella* has a calcareous conch commonly in the form of a high, narrow, radially symmetrical cone closed at the apex. Into this simple cone the animal presumably placed grains around a central fleshy area, now represented as a tube filled either with sparry calcite or with matrix. In an unnamed species from western Nevada, attributed to *Salterella,* Yochelson, Pierce & Taylor (1970) demonstrated that this calcareous conch was filled with quartz, zircon, and a limited variety of discrete heavy mineral grains; virtually none of the grains were of carbonates. Subsequently, Yochelson (1970) redescribed *Salterella conulata* Clark, showing laminae of calcium carbonate within the cone.

Two objections have been informally raised by colleagues regarding the interpretation of laminae within a conch of *Salterella.* First, it has been argued that the genus *Volborthella,* also of late Early Cambrian age, collected discrete mineral grains into laminae within an organic tube; by inference, this can be extended to suggest that there is a fundamental difference between the two genera because of differences in the conch or tube, even though Yochelson, Pierce & Taylor found a calcareous tube external to the layers of mineral grains. Second, it has been argued that *Salterella* actually shows two layers comparable to the shell of many mollusks; in this interpretation, the cone would be an outer shell layer, and the presumed laminated filling would be an inner shell deposited by tissue at a slower rate than the outer layer.

Our data show that in a *Salterella* having a calcareous interior the inner material is in the form of discrete grains, mainly of dolomite, and that therefore both arguments are null.

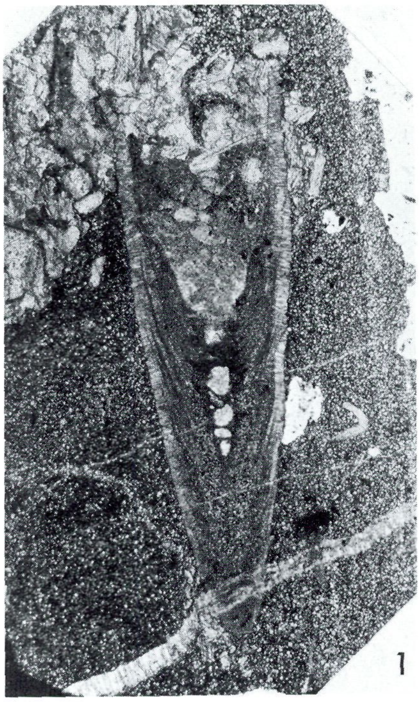


Fig. 1. Thin section illustrated by Poulsen (1932) as Pl. 8, fig. 1. The section is almost perfectly longitudinal and shows the central tube, now filled with sparry calcite, extending downward from the apertural cavity. MMH 3568. × 10.

Fig. 2. Thin section illustrated by Poulsen (1932) as Pl. 8, fig. 2. This section is cut essentially parallel to the central tube but misses it. As originally presented, both sections had some of the laminae accentuated by inked lines. MMH 3567. × 10.

Fig. 3. Part of MMH 3568. × 50. The conch walls appear as fibrous calcite, especially to the upper left; the laminae and calcite near the wall are interleaved light and dark, the thicker part of the laminae being darker interspersed with light specks. The filling of the apertural cavity is finer grained than the matrix, the central tube below being filled mainly by sparry calcite. Note how the laminae lap onto the wall and thin toward the aperture.

The two thin sections figured by Poulsen (1932, pl. 8) are refigured as figs 1 & 2, respectively, and admirably show many petrographic details.

Optical examination of *S. rugosa*

Examination under direct and polarized light shows that the matrix surrounding specimens of *S. rugosa* consists of carbonate in a coarse grain-growth matrix; calcite is predominant, but scattered dolomite rhombs are present. Many calcite grains are elongated normal to the outer walls of *Salterella* conchs.

The carbonate filling the apertural cavity is typically finer grained than the matrix (fig. 3). It shows the variable grain size, irregular grain shape, and sutured grain boundaries, typical of micrite recrystallized by the process of grain growth (Bathurst 1958). Scattered dolomite rhombs in the apertural area are intermediate in size between the largest and smallest of the recrystallized calcite grains.

Inside the specimens, dolomite and calcite both occur, dolomite grains being very abundant. Calcite appears more common in thin layers between concentrations of dolomite grains. A few grains of feldspar and of quartz are irregularly interspaced with the dolomite.

Opaque grains are rare; they have been identified as hematite flakes by their hexagonal shape and are in the form of thin plates. The hematite flakes are not oriented at random, but are arranged around the central tube, more commonly near the central part of the inner filling than around the periphery. Flakes are neither flat nor on end relative to the tube but stand parallel to the inclined laminae and help to delineate them. Thus, when viewed in longitudinal or saggital section, they do not show an ideal crystal form. Although there is considerable variation among the laminae, in general, individual grains are more abundant near the central tube, and proportionally greater thicknesses of calcite are present near the conch wall (fig. 4).

A few opaque cubic crystals also occur. These most likely are pyrite and could have been formed diagenetically, perhaps aided by decay of soft parts within the central tube.

Recrystallization of calcite results in a matrix that appears significantly coarser than that within the *Salterella* tube (fig. 5). The welding of thin laminae of calcite onto the inner surface of the conch wall results in an irregular-appearing region; the outer surface of the wall is modified slightly by pressure solution of the calcite. It is impossible to determine the original mineralogy or structure of the outer wall in this species.

Electron-probe examination of *S. rugosa*

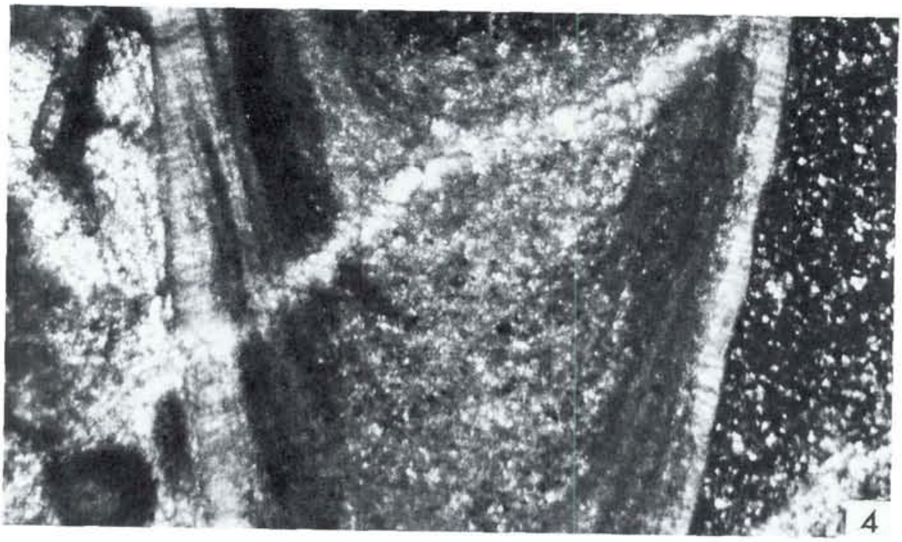
An additional thin section was cut and coated with carbon for investigation by electron probe. Distribution maps for Ca and Mg (figs 6 & 7) show that dolomite is completely absent from the outer conch and virtually absent from the filling in the apertural cavity. Although no dolomite is visible in the surrounding matrix in this particular view, many isolated grains were found in other areas of the matrix.

In contrast to the outer shell, the laminae show strong planar concentrations of dolomite as discrete, angular grains, almost all of which are between 5 and 10 μm in largest dimension (figs 8 & 9). The scattered grains of quartz and feldspar within these dolomite-rich layers are of approximately the same size. These accumulations of clastic grains are cemented together by interstitial calcite, and the granular laminae are separated from one another by layers of calcite.

The calcite of the matrix, the outer shell, and the laminae was analyzed for Mg and Sr, but no significant differences were found; in all analyses the contents of both elements were less than 0.1 wt %

Discussion

The occurrence of *Salterella* associated with a carbonate matrix containing small amounts of fine-grained dolomite is a fortuitous one. Two other species of *Salterella* were examined by electron probe with negative results. A specimen of *S. conulata,* from Landis Valley near Lancaster, Pennsylvania (Yochelson 1970, p. B



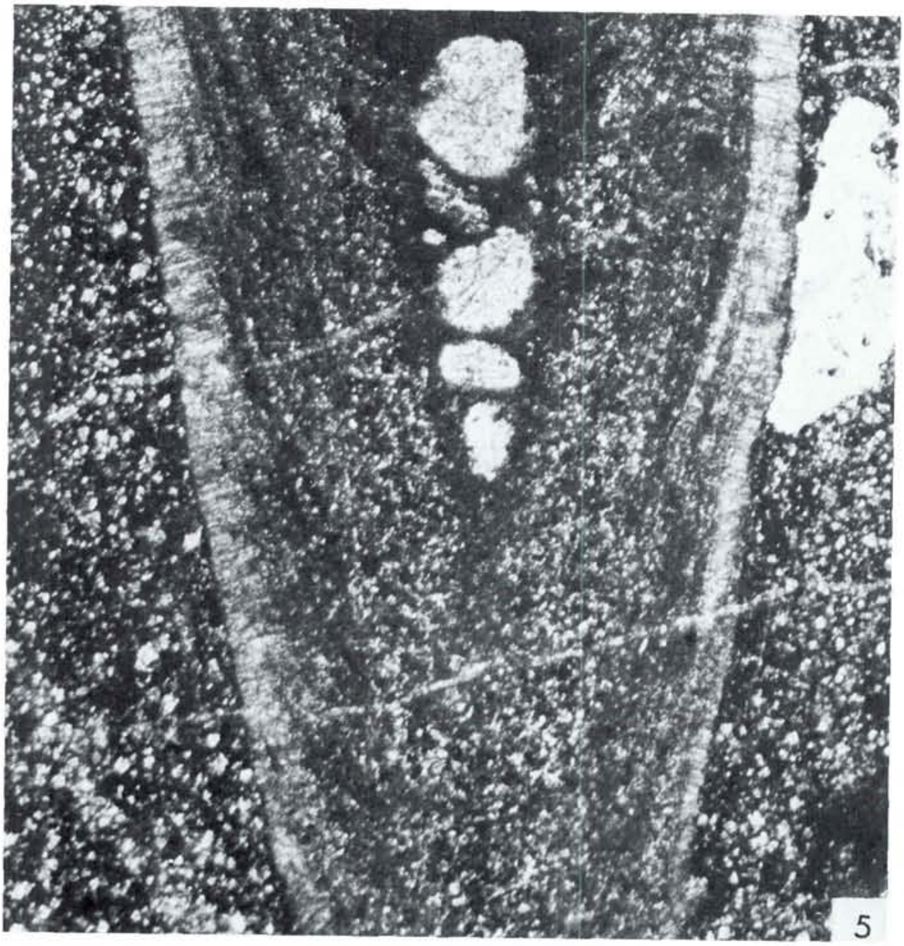


Fig. 4. Part of MMH 3567. × 50. The variation in thickness and content of some laminae may be seen. Rare opaque mineral grains are present. The grainy texture of much of the laminated area contrasts strongly with the area near the conch wall; this wall in turn contrasts strongly with the laminations.

Fig. 5. Part of MMH 3568. × 50. The finer texture of the material within the Salterella *tube is apparent, as is the presence of more grains near the middle of the tube and few near the wall. Although much recrystallization has taken place in a few areas, particularly at the upper left, the distinction between the alternating calcite and dolomite layers of the laminae and the calcite of the outer shell is clear.*

7), contained a large amount of dolomite in the matrix, but only calcite in the laminations and within the apertural filling. Apparently, the specimen was moved after death into an area of dolomite deposition. Alternatively, penecontemporaneous dolomitization occurred after death of the organism, but did not affect the material of the apertural filling because of microenvironmental differences between this area and the sediment itself. An undescribed species of *Salterella,* from Thomasville, Pennsylvania (Yochelson 1970, p. B7–B8), showed no diagenetic alteration of exceedingly pure limestone, but the individual grains of carbonate were so small that it was difficult to resolve them even with the microprobe.

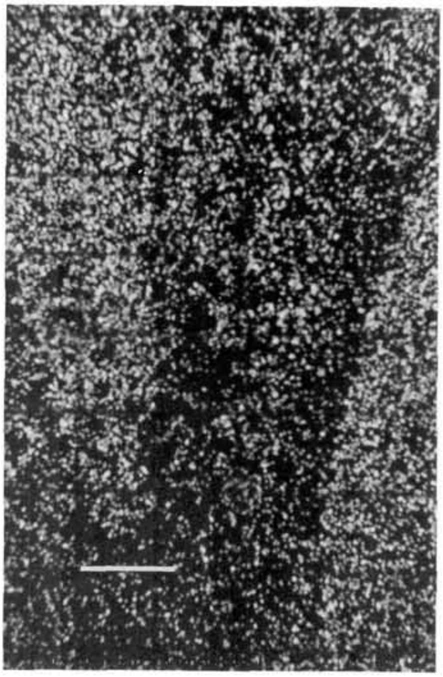
The joint occurrence of calcite and dolomite in the matrix of the Ella Ø Formation, along with very rare grains of other minerals, allowed the specimens of *Salterella* some latitude in selecting desired grains. Yochelson, Pierce & Taylor (1970) discussed the concentration of zircon from an orthoquartzite in a *Salterella* and concluded that the organism assembled small grains; the heavy mineral grains were hydrodynamic equivalents of larger quartz grains that make up the matrix. The dolomite grains might have been slightly smaller than associated calcite grains because of the slightly greater density of dolomite; under weak current sorting they would form hydrodynamic equivalents in the sediment. However, we do not consider this a feasible explanation. Rather, we suggest that the animals lived on a surface of carbonate, the calcium carbonate being impalpable mud. Dolomite rhombs scattered through this soft sediment constituted most of the 'hard particles' available. Occurrence within the dolomite-rich laminations of occasional grains of 'foreign' feldspar and quartz, which are exceedingly rare in the carbonate matrix, is further proof that the animal selected for grain size rather than grain composition.

The organism was, in a sense, indifferent to the composition of the available grains. In an environment of quartz grains, *Salterella* picked up mainly such grains, whereas in a carbonate environment, the organism picked up calcite and dolomite. Although it was apparent earlier, these new data reinforce the point that mineral content of the laminations cannot be used as a systematic character.

Likewise, the presence of large amounts of dolomite within the laminations eliminates the possibility that this area can be homologized with the inner shell layer of mollusks. Although some mollusks are known that have the ability to secrete one layer of calcite and a second of aragonite, none are known to secrete dolomite. Even if one were to suggest for purposes of speculation that early mollusks might have had this ability, the intermixture of grains of calcite and other noncarbonate minerals within the predominately dolomitic laminae effectively destroys this speculation.

Because of their regularity, it is obvious that the laminations are not an infilling after death of the animal. The alternation of a layer composed predominantly of dolomite grains, with a layer mainly of calcite, suggests that a layer of grains was emplaced behind the main body of the animal and that calcite then was secreted to cement this layer in place. After cementing, another layer of grains was added. This possibility was suggested by J. W. Pierce (oral communication, July 1969) after examining specimens of *Salterella* n. sp. mentioned above, but it could not be demonstrated because calcite grains were cemented by calcite. The bonding of dolomite grains by calcite provides proof of the layer-by-layer deposition. No diagenetic phenomenon with which we are familiar could have produced the laminations. Granular layers of dolomite commonly are thicker than the calcite layers, but there is considerable irregularity both during growth of an individual and between individuals.

The Early Cambrian was a time in which many atypical animals experimented with various modes of life. The emplacement of grains to partially fill a tube was not a successful experiment over a long geologic time. In order to select desired grains from the environment and to concentrate them within the conch, the animal had to have sufficient mobility and a well-developed tactile sense. The terms 'primitive' or 'archaic', therefore, are not appropriately applied to such a sophisticated mode of life.



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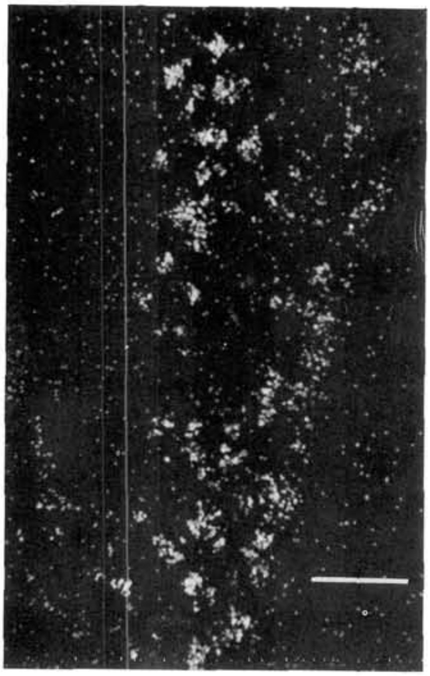

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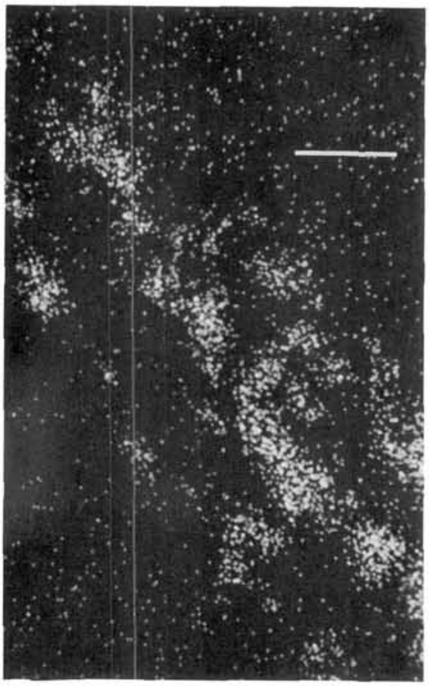

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Fig. 6. Ca Kα distribution map of part of thin section MMH 13.413 cut from rock MMU 1936.125, showing the lower abundance of calcite in the laminations (dark part) compared with the outer conch (to right) and the apertural filling (to left). This map was made of an area comparable with that shown in fig. 1 on the lower right side between the base of the exposed central tube and the apex. Scale bar equals 100 μm. (× 110).

Fig. 7. Mg Kα distribution map over same area as in fig. 6, showing concentration of dolomite grains (light patches) in the laminations. Scale bar equals 100 μm (× 110).

Fig. 8. Mg Kα distribution map showing planar concentration of dolomite grains (light colored) alternating with laminae of calcite (dark colored). Scale bar equals 10 μm (× 1200). This map was made of an area comparable with that shown on fig. 1 on the lower right side between the large calcite crystal on the exterior and the fine vein below cutting matrix and specimen; it is included in the area shown in fig. 7.

Fig. 9. Mg Kα distribution map showing planar concentration of dolomite grains (light colored) alternating with laminae of calcite (dark colored). Scale bar equals 10 μm (× 1200). This map was made of an area comparable with that shown on fig. 1 at the upper left midway between the rim of the aperture, seen in the midst of sparry calcite, and the shell apex below.

Dansk sammendrag

Salterella rugosa fra Ella Ø Formationen, Øst Grønland, udvalgte dolomitkorn fra et substrat bestående af calcit og dolomit og placerede disse på indersiden af deres calciumcarbonat-skaller. Kvarts, feldspat og hæmatit findes også i de dolomitrige lag på indersiden af skallerne. Elektronmikroprobe-undersøgelser bekræfter, at de dolomitrige lag er adskilt af tynde lag af calcit. Dette indebærer, at dyrene anbragte et lag af udvalgte sedimentkorn og derpå cementerede dem sammen, før de samlede korn til anbringelse i det næste lag.

References

Bathurst, R. G. C. 1958: Diagenetic fabrics in some British Dinantian limestones. *Liverpool-Manchester geol. J.* 2, 11–36.

Poulsen, C. 1932: The Lower Cambrian faunas of East Greenland. *Meddr Grønland* 87 (6), 67 pp.

Yochelson, E. L. 1970: The Early Cambrian fossil *Salterella conulata* Clark in eastern North America. *U.S. geol. Survey Prof. Paper* 683-B, 1–10.

Yochelson, E. L., Pierce, J. W. & Taylor, M. E. 1970: *Salterella* from the Lower Cambrian of central Nevada. *U.S. geol. Survey Prof. Paper* 643-H, 1–7.