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CHLOROPLAST IN SPIROGYRA FROM THE GREEN RIVER FORMATION OF WYOMING*

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ABSTRACT. A remarkable assemblage of micro-organisms, mostly algae, was found in a thin stratum of exceptionally rich oil shale from the Wilkins Peak member of the Green River formation of Eocene age. In this microflora is an almost perfectly preserved germling cell of *Spirogyra*, which still contains its spiral chloroplast. The cell is turgid and the dark-colored chloroplast appears to be suspended in a nearly colorless, transparent matrix. The preservation indicates that either the cell wall successfully resisted destructive attack by bacteria or saprophytic fungi or that, by chance, it actually was not attacked. The fact that this cell has retained its rounded, turgid form during the full compaction of the enclosing sediments implies that the cell wall was permeable enough so that virtually perfect hydrostatic balance was maintained between the fluids within and outside the cell. Certain other algal cells were flattened to a mere film and cracked radially. The organic ooze in which these organisms were preserved must have remained plastic during the whole process of compaction. This inference is supported by the fact that the thin varves in other nearby oil shale layers were distorted (locally) into sharply pointed peaks by the growth of shortite crystals. Such peaks would surely have lost their sharp crests had they formed before compaction had been completed.

A layer of exceptionally rich oil shale, 2 mm thick, from the saline facies of the Wilkins Peak member of the Green River formation of Wyoming was found to contain a remarkable assemblage of micro-organisms. The Green River formation is lower to middle Eocene and middle Eocene, which, according to Kulp (1961), is about 52 million years old. This thin oil shale stratum represents a brief, relatively high water stage of Gosiute Lake when the lake was meromict and the epilimnion probably was thin enough to admit light to the chemocline. An abnormal abundance of pyrite in the oil shale (about 25 percent by weight) suggests that photosynthetic sulfate-reducing bacteria prospered just above, or within, the chemocline. Below the chemocline the more saline monimolimnion, as in most meromict lakes, must have been charged with hydrogen sulfide. The climate at that stage of the Green River epoch was about as dry as that of the present valley of Great Salt Lake, though it was considerably warmer. During the summers the epilimnion was so warm that a diversified, pondlike algal flora prevailed. This algal flora and the associated micro-organisms will be described elsewhere.

The purpose of this brief paper is to call attention to the remarkable preservation of the spiral chloroplast in a germling cell of *Spirogyra* (fig. 1). This fossil alga is so nearly like sprouts of the living *Spirogyra velata* Nordstedt figured by West (1904, fig. 49, p. 133), and copied here as figure 2, that one might be tempted to assign it to the same species. A new species name will be given it, however, to signalize its remarkable state of preservation.

The fossil *Spirogyra* cell is turgid and has no discernible break in the cell wall. The spiral chloroplast appears to be suspended in a nearly colorless, transparent matrix. The chloroplast itself is nearly opaque and is a dark reddish brown, which is comparable to the color of the cell walls of many of the algae and fungi found in oil shales of the Green River. The cell and its contents give the impression that it has been preserved by a sort of mummification in

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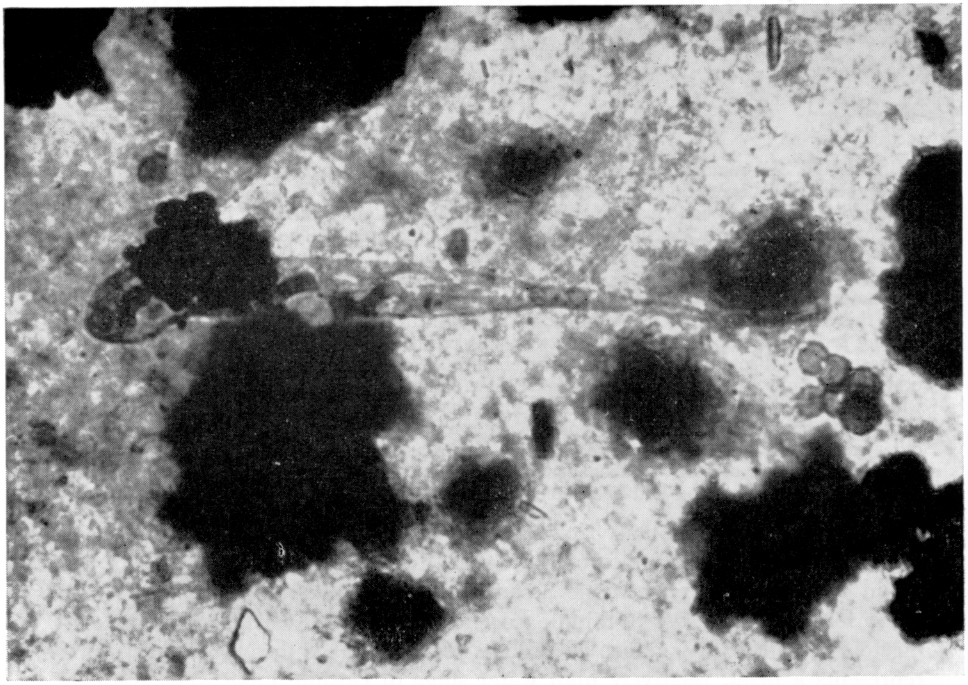

Fig. 1. Germling of the green alga *Spirogyra* sp. containing its spiral chloroplast. The single cell, which is 0.2 mm long, is embedded in very rich oil shale. The black areas are pyrite crystals and near the tapered end of the *Spirogyra* cell is a group of small, unidentified algal cells.

which there was no distortion and either no shrinkage or perfect cubic contraction of the cell and its contents.

The preservation of the chloroplast in this *Spirogyra* sprout indicates either that the cell wall successfully resisted destructive attack by bacteria or saprophytic fungi or that, by chance, it was actually not attacked. The fact that so many well preserved algal cells and other micro-organisms escaped destruction implies that the organic gel itself, or the products of the decomposition that gave rise to the organic gel, were inimical to the growth of anaerobic bacteria.

In living species of *Spirogyra*, and other members of the Order Zygnematales, the cell wall is cellulosic and has an outer layer of pectose (Smith, 1933, p. 534). The chloroplast, on the other hand, is a modified part of the cell protoplasm, which is packed with chlorophyll and other pigments and

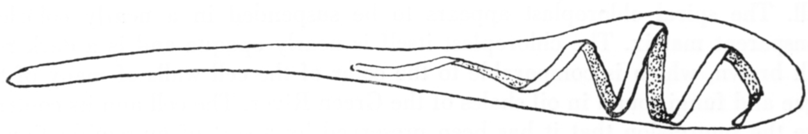

Fig. 2. Germling of *Spirogyra velata* Nordstedt drawn from West (1904, fig. 49, p. 133) to the same scale as figure 1.

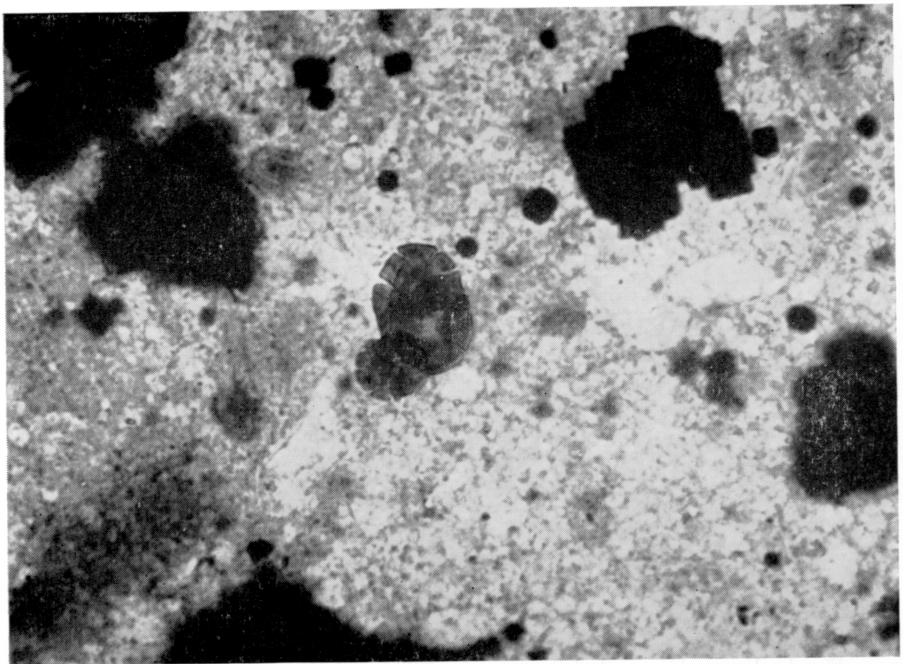

Fig. 3. Flattened and ruptured algal cells found in the same thin section of rich oil shale that contains the *Spirogyra* germling. The larger *Chroococcus*-like cell is about 0.034 mm long.

which has a greater density than the cytoplasm (Schussnig, 1960, v. 2, p. 199). According to Weier (1961, p. 220), chloroplasts are surrounded by a membrane. Such a bounding membrane, even though extremely thin, would help explain the sharply defined boundaries of the spiral chloroplasts in the Zygmatales.

It is altogether remarkable that such a structure should be preserved long enough to have become fossilized. One might speculate that, since derivatives of chlorophyll and other plant pigments have been shown to persist in organic-rich sediments for long intervals of time (Vallentyne, 1955, p. 309), that the chloroplast in this fossil *Spirogyra* cell now consists of "humified" derivatives of chlorophyll. But what of the cytoplasm that presumably must have supported the chloroplast until it was "humified"? Was it also humified by the same process and at the same time? Answers to such questions may one day come from the important research of J. R. Vallentyne on the preservation in lacustrine sediments of plant pigments and other organic substances.

The fact that this algal cell has retained its rounded, turgid form during the full compaction of the enclosing sediments has some interesting implications. In the first place, it seems necessary to assume that the cell wall was permeable enough so that virtually perfect hydrostatic balance was maintained between the fluids within and outside the cell during the whole long process of compaction of the Green River formation—a process that must have lasted a great many years, perhaps to be measured in the millions. Many other algal

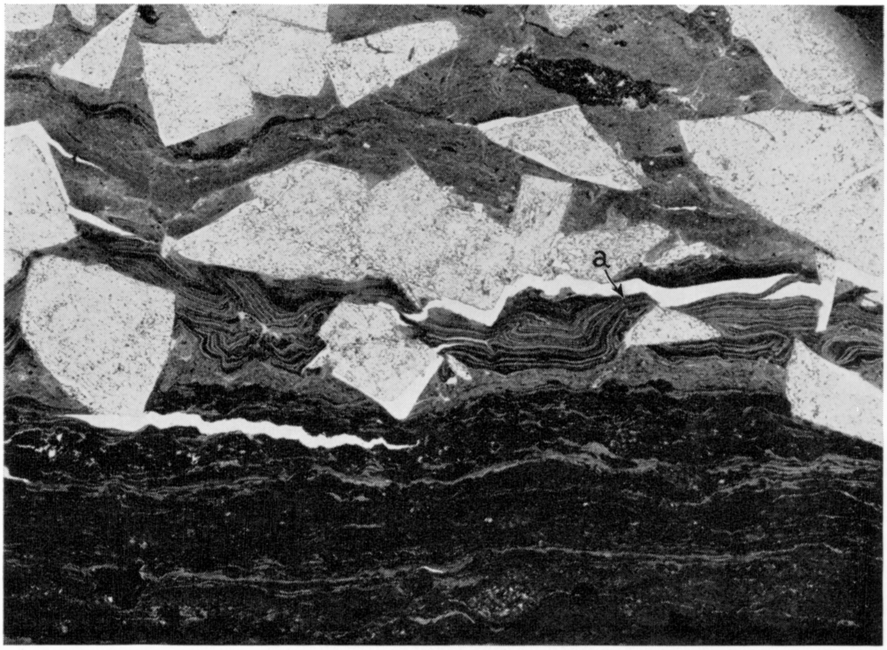

Fig. 4. Varves in an oil shale from the Wilkins Peak member of the Green River formation, Sweetwater County, Wyoming, showing distortion by shortite crystals that grew in the still-plastic sediment after maximum compaction. Under a microscope it can be seen that the varves are very much thinned and stretched around the margins of crystals, which at this magnification appear to cut the varves. × 10.

cells in this oil shale also retained their turgidity but some did not. These latter are flattened to a mere film in the plane of the bedding and, during compaction, cracked open, generally along radii (fig. 3). This complete flattening of some algal cells while others retained their rotundity excludes the interpretation that the organic ooze, or gel, became rigid early in the diagenetic process and thereby prevented further compression of algal cells. Indeed, there are other reasons, such as exceedingly thin varves, which indicate that the original layers of organic ooze thinned even more than the associated layers containing less organic matter.

A second implication appears to follow from these relationships between rotund and completely flattened algal cells. The organic ooze must have remained soft and plastic during the whole process of compaction. This inference is independently supported by the fact that the varves in other nearby oil shale layers were plastically deformed by the growth of shortite crystals after full compaction of the oil shale (fig. 4). Such peaks as that at *a* in this figure would surely have lost their sharp crests had they formed before compaction had been completed.

Inasmuch as one algal cell with its chloroplast preserved intact has been found in oil shale of the Green River formation, it is reasonable to expect others among the remarkable microfossils in this formation.

REFERENCES

Kulp, J. L., 1961, Geologic time scale: Science, v. 133, p. 1111.

Schussnig, Bruno, 1960, Handbuch der Protophytenkunde, v. 2: Jena, Gustav Fischer, 199 p.

Smith, G. M., 1933, Fresh-water algae of the United States: New York, McGraw-Hill Book Company, 716 p.

Vallentyne, J. R., 1955, Sedimentary chlorophyll determination as a paleobotanical method: Canad. Jour. Botany, v. 33, p. 304-313.

Weier, T. E., 1961, Chloroplast, *in* Gray, Peter, ed., The encyclopedia of the biological sciences: New York, Reinhold Publishing Corporation.

West, G. S., 1904, The British freshwater algae: Cambridge, Cambridge University Press, 372 p.