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STUDIES ON THE REPRODUCTIVE ORGANS OF RED ALGAE

II. On *Erythrophyllum Gmelini* (GRUN.) YENDO

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The red alga, which has hitherto been known under the name of *Erythrophyllum Gmelini* since Yendo (1915) identified it with *Kallymenia Gmelini* Grunow (1870) and proposed to transfer the species to Erythrophyllum, is distributed widely in the Kurile Islands (Nagai, 1941, p. 174-5) and in the eastern districts of Hokkaido ranging from Kushiro to Nemuro (Okamura, 1921, p. 94). It was also reported from Agattu Island, Alaska, by Setchell and Gardner (1903, p. 307) and Atka Island, Aleutian Islands, by Okamura (1933, p. 89).

The external and internal structures of the vegetative thallus of the alga were thoroughly described and illustrated by Yendo (1915) and Okamura (1921, pl. 172). On the other hand, its reproductive organs have been unknown to the previous authors such as Yendo (l. c.) and Nagai (l. c.) and quite imperfectly known from only the brief remarks on the cystocarp given by Setchell and Gardner (1903, p. 308) and Okamura (1933, p. 89).

The mature cystocarpic specimens of this alga were collected by the junior writer on March 27, 1945, for the first time, and secondly on March 12, 1949, at Shireto Point in the outskirts of Kushiro City, Hokkaido. A provisional report on the writers' observations of the cystocarp was presented in September 1949 and in November of the same year before the Hokkaido regional conference of the Japanese Society of Scientific Fisheries held in Hakodate and that of the Botanical Society of Japan held in Sapporo respectively.

With the object of obtaining more materials of the female plant and also, if possible, male and tetrasporic specimens, collections of the alga were repeated at the same place in other months, *i. e.*, in April, May, October and November. The writers were fortunately successful in collecting the immature tetrasporic individuals for the first time in late November 1955. Being encouraged by this discovery, the writers asked Mr. Shigeru Sasaki of the Kushiro Branch of the Hokkaido Fisheries Experimental Station to collect the plant at Shireto Point in January and February. Mr. Sasaki's collections made in the middle of January and in early February 1956 contained, just according to expectation, a large number of mature tetrasporic specimens and several young cystocarpic ones. In the course of the present study the writers came across a few specimens

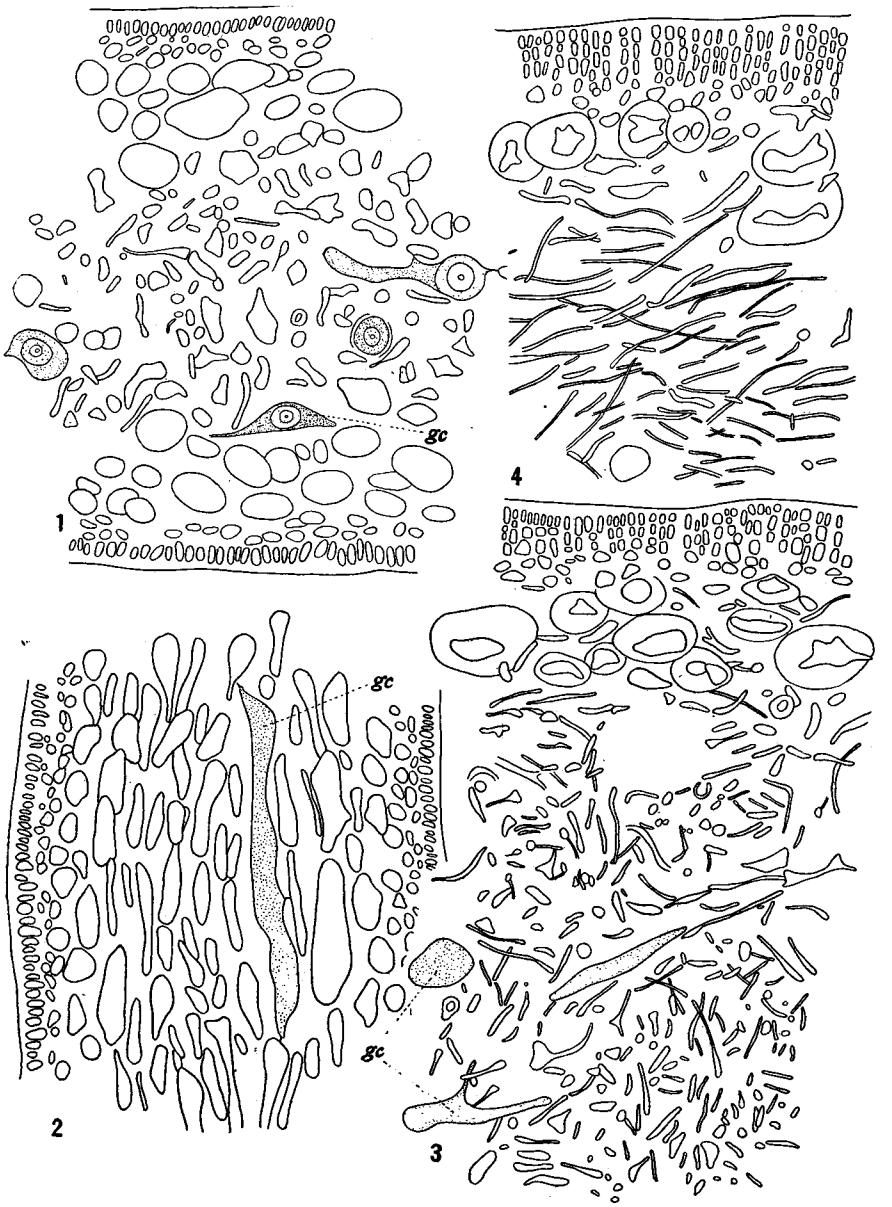


Fig. 1. Cross section of the upper segment of a frond. *gc*, giant cell × 275
Fig. 2. Vertical section of the upper segment of a frond. *gc*, giant cell × 275
Fig. 3. Cross section of the lower stem-like portion of a frond. *gc*, giant cell × 275
Fig. 4. Vertical section of the lower stem-like portion of a frond × 275

of the present alga collected by Mr. T. Inaba at Akkeshi, Prov. Kushiro, on June 16, 1938, and found that one of them was bearing mature cystocarps. Thanks to these fertile materials it is now possible to discuss the systematic position of the plant with certainty. Here the writers wish to acknowledge their indebtedness to Mr. S. Sasaki for his valuable assistance. The writers' sincere thanks are also due to Mr. M. Sakurai, director of the above mentioned Branch, who afforded the writers many facilities for the present study, and to Mr. T. Inaba for his nicely preserved specimens presented kindly to the senior writer.

The female plant collected in November can be distinguished from the sterile or tetrasporic individuals by its possession of faintly dark brown colored strands along the longitudinal axis of the upper segments of the frond. Sections through these strands reveal here and there the presence of the procarps of a characteristic structure. Later on these strands become more dark in color as may be seen in the specimens collected in January and February. Carpospores are already produced in those specimens, but they are not yet so fully matured as to form cystocarps. The cystocarps are observed in the specimens collected in March 1945 and 1949 as mentioned above, in the form of small elliptical rings, in surface view, elongated in the direction of the frond axis, and scattered separately or in irregular confluent groups in the upper segments of the frond. The cystocarps themselves do not push up the frond surface, but the frond portion that contains cystocarps is slightly thickened as a whole. Such a ringlet-shaped cystocarp has not been described in any other known species of Florideae, so far as the writers have been able to find. The new generic name, Cirrulicarpus, proposed in this paper for the present alga, is based on this characteristic appearance of the cystocarp.

The structure of the procarp, the development of the gonimoblast, and the character of the tetrasporangia in the present alga are described as follows. The male reproductive organ is not observed yet.

The carpogonial branch consists of six cells arranged in a strong curve. The basal cell, which is the largest and more or less irregular in shape, is situated so closely beneath the carpogone that the writers are strongly inclined to interpret it as the auxiliary cell though they have not been successful in observing the actual fusion between it and the carpogone.

After fertilization, all cells of the carpogonial branch except the carpogone fuse with each other to form a large fusion cell of irregular shape. The fusion cell has several narrow protuberances which issue in all directions; each of them gives rise to a gonimoblast initial. Almost all of the gonimoblast cells seem to become carpospores. The mature cystocarp is composed of many small groups of carpospores and the groups are separated from each other by a few vegetative filaments. There is no special pericarpic tissue nor carpostome. The manner of freeing the carpospores was not observed.

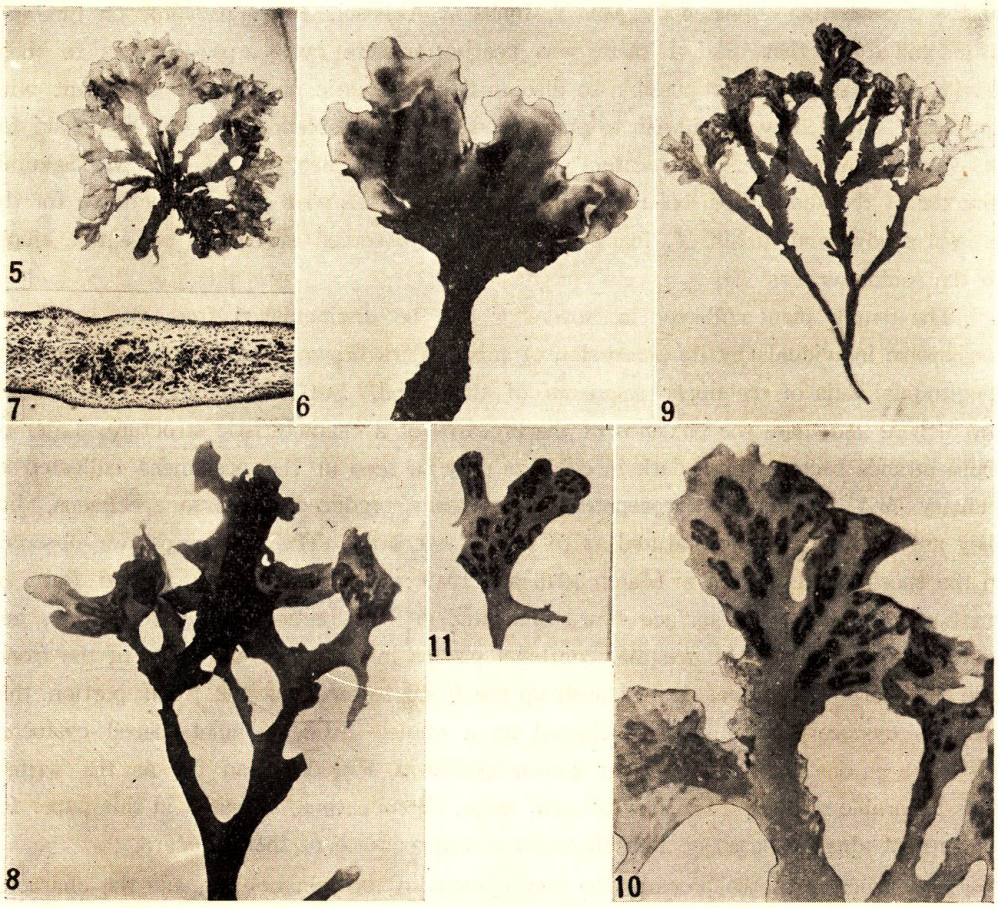


Fig. 5. Photograph of a young female plant collected at Shireto Point, Kushiro, 30 Nov. 1955 × 1/3

Fig. 6. Photograph of an apical segment of the plant shown in Fig. 5, to show the dark colored strands on the surface × 1.5

Fig. 7. Microphotograph of a cross section through the strands of the plant shown in Fig. 5 × 28.5

Fig. 8. Photograph of the upper part of a mature female plant preserved in formalin seawater to show the cystocarps on the surface of the apical segments × 1/3

Fig. 9. Photograph of a herbarium specimen of the mature female plant collected by Mr. T. Inaba at Akkeshi, Prov. Kushiro, 16 June 1938 × 1/3

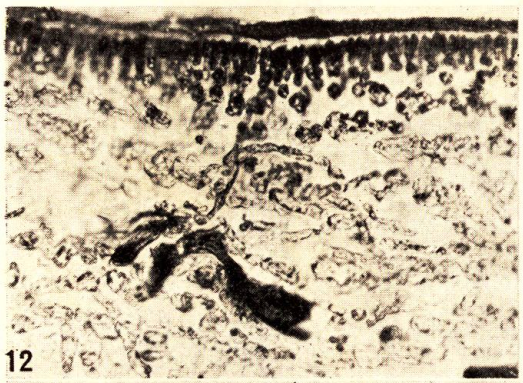
Fig.10. Photograph of the central apical portion of the specimen shown in Fig. 9, to show the cystocarps × 1.5

Fig.11. Photograph of an apical fragment from the specimen shown in Fig. 9 × 1.5

The tetrasporophyte does not differ from the female plant in general appearance of the frond, but when matured it looks dark reddish in color to the naked eye. The tetrasporangia are scattered without any order all over the frond surface with the exception of the stem-like lower portion. They are not among the superficial cells but

are arranged in one layer beneath one to two layers of cortical cells, being transformed from the subapical cell of the anticlinal row of cortical cells. In other words, the development of the sporangia is not apical but intercalary. The sporangia are obliquely cruciate in division.

As understood by the above description of the reproductive organs, the alga in consideration cannot be placed in the genus Erythrophyllum as has been done by Yendo nor in the genus Crossocarpus as suggested with reservations by the same author. Erythrophyllum is characterized by several peculiarities of reproductive organs as described and illustrated by Twiss (1911) in its type species, *E. delesserioides* J. Ag. In that species, the cystocarps and tetrasporangia are formed in papillae which densely cover the frond surface, and the tetrasporangia are not intercalary but apical. Crossocarpus, represented by the single species *C. lamuticus* Rupr., is characterized by the possession of cystocarps in the leaflets that fringe the frond margins.



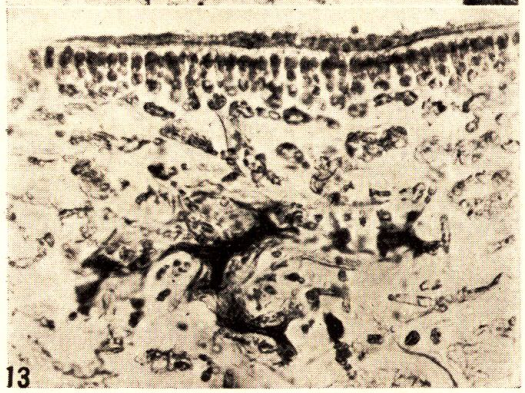


Fig. 12. Microphotograph of a section through a fertile segment of the female plant to show carpogone. (cf. Fig. 15) × 277

Fig. 13. Microphotograph of a fusion cell formed by the carpogonial cells after fertilization (cf. Fig. 16) × 275

As discussed by Yendo (1915), *Erythrophyllum delesserioides*, *Crossocarpus lamuticus* and the present alga all possess common peculiarities in the structure of thallus and in having a yellowish homogeneous substance in some of the medullary cells. The content of such cells in the present alga was proved to show the reaction of protein by

Fig. 14. Microphotograph of a fusion cell giving rise to gonimoblast initials. (cf. Fig. 17) × 215

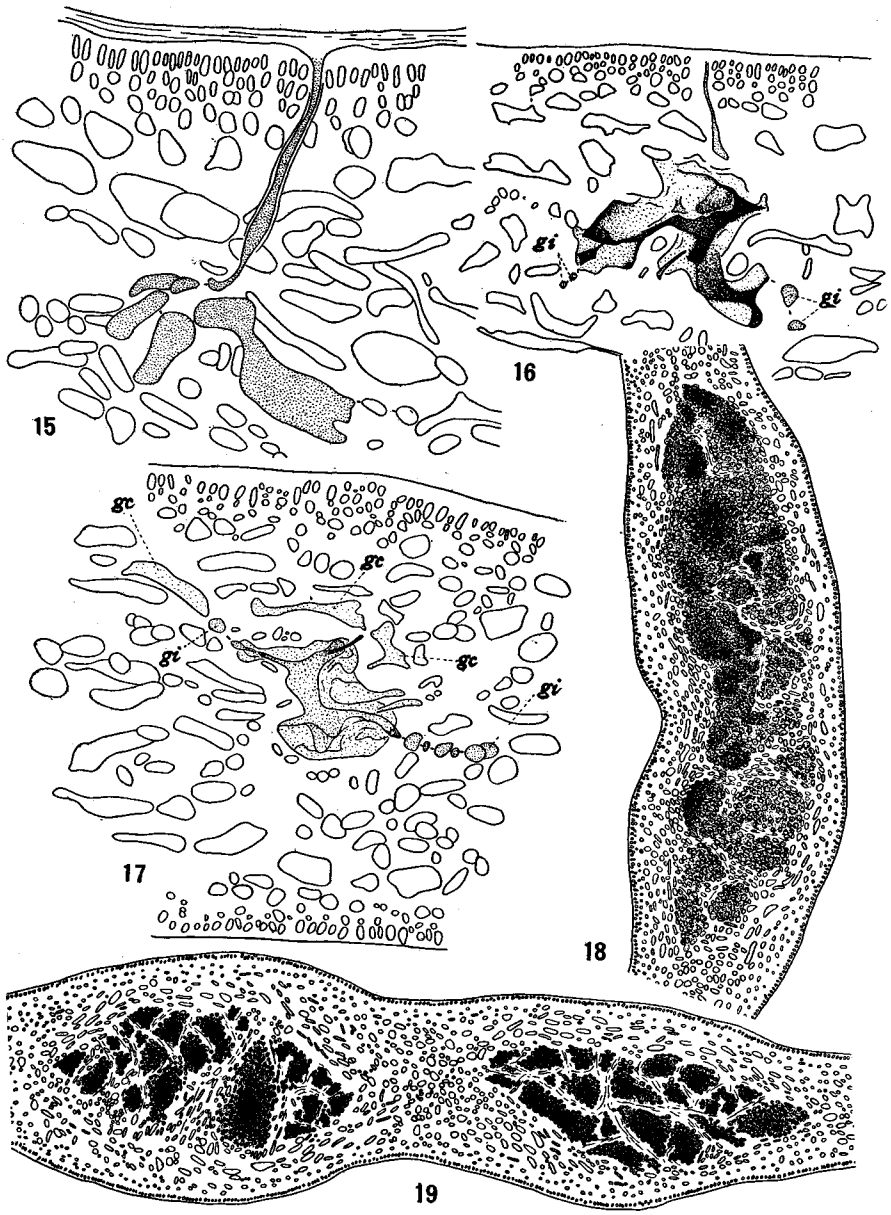


Fig. 15. Camera lucida drawing of the section shown in Fig. 12 × 400

Fig. 16. Camera lucida drawing of the section shown in Fig. 13. *gi*, gonimoblast initial × 275

Fig. 17. Camera lucida drawing of the section shown in Fig. 14. *gc*, giant cell; *gi*, gonimoblast initial × 275

Fig. 18. Longitudinal section through a mature cystocarp to show small groups of carpospores × 75

Fig. 19. Cross section through a cystocarp ringlet × 75

treating with Millon's reagent and to show high density of protoplasm by staining with lactic blue.

In referring the present alga to *Kallymenia Gmelini* Grunow (1870), the writers follow the opinion of Yendo (1915) who examined the original specimens preserved in the Botanical Museum of Berlin. However, such characteristics of the reproductive organs as described above would not allow us to place the species in the genus Callymenia, nor Erythrophyllum, nor any other genus ever described. So the writers wish to establish a new genus for the species and propose to call the present alga *Cirrulicarpus Gmelini* as described below. The new genus is to be classified in the Callymeniaceae.

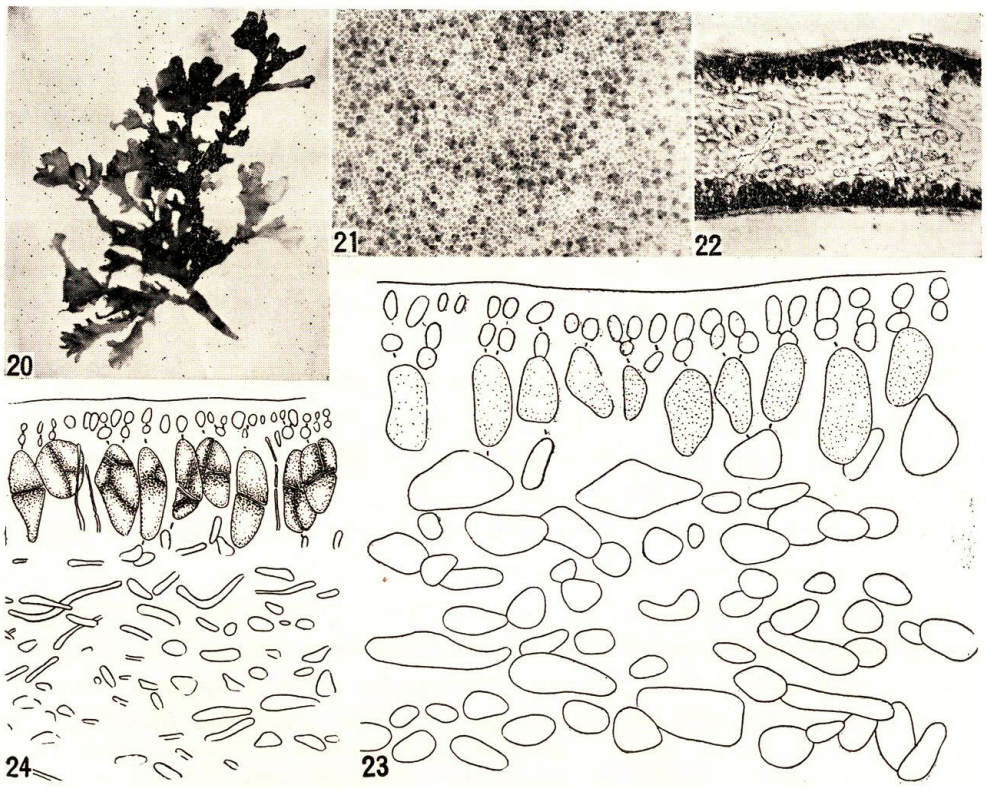


Fig. 20. Photograph of a living tetrasporic specimen, collected at Shireto Point, Kushiro, 30 November 1955 × 1/4

Fig. 21. Microphotograph of the surface of a segment bearing young tetrasporangia × 93

Fig. 22. Microphotograph of a section through the segment bearing young tetrasporangia × 212

Fig. 23. Section through the segment bearing young tetrasporangia to show their intercalary development × 400

Fig. 24. Section through the segment bearing mature tetrasporangia to show their various dividing modes × 275

Cirrulicarpus Tokida et Masaki, gen. nov.

Frond carnoso-membranous, dichotomously or palmately laciniate, consisting of three layers; medullary layer thick, composed of vertically elongated, often filamentous colorless cells and a few scattered gigantic cells with yellowish homogeneous content; subcortical layer composed of a few layers of roundish oblong colorless cells; superficial cortical layer composed of one to three layers of small colored cells in the upper segments and anticlinal rows of several small colored cells in the stem-like lower portion of the frond. Cystocarps in the shape of ringlets, scattered on the surface of the upper segments, composed of small groups of carpospores separated from each other by a few vegetative filaments. Tetrasporangia scattered over the frond surface in one layer beneath the superficial cell layer being transformed from intercalary cortical cells, obliquely cruciate in division. Antheridia unknown.[1)]

Cirrulicarpus Gmelini (Grunow) Tokida et Masaki, nom. nov.

Kallymenia Gmelini Grunow, Alg. Exped. Novara, p. 72, 1870 (specimens from the Kurile Islands: *after* Yendo, 1915); Setchell and Gardner, Alg. N.-W. Amer., p. 307, 1903.

Erythrophyllum Gmelini (Grun.) Yendo, *in* Bot. Mag., Tokyo, **29** (346), p. 230–237, figs. 1–3, 1915; Okamura, Icon. Jap. Alg., **4** (5), p. 90, pl. 172, 1921; *Id.*, Alg. Alaska, p. 89, 1933; *Id.*, Nippon Kaisô-shi, p. 573, fig. 268, 1936.

Japanese name: *Yezo-tosaka* (Okamura).

Type locality of the specimens employed for the establishment of the present new genus: Shireto Point, Kushiro City, Hokkaido (Masaki, 25 March, 1945, October 1948, 12 March 1949, 15 April 1949, 25 November 1949, 14 May 1955, 30 November 1955; Sasaki, 14 January 1956, 2 February 1956).

Distribution: Eastern coasts of Hokkaido from Prov. Kushiro to Prov. Nemuro; the whole Kurile Islands; Aleutian Islands; Alaska.

To avoid superfluousness, here will be given no description of the species other than some data obtained by the measurement of the reproductive organs. The size of the cystocarp ringlets as seen from the frond surface in the formalin specimens is 4.5 × 1.9 mm on the average of 17 samples ranging from 6 to 3 mm and from 3 to 1 mm

1) Cirrulicarpus Tokida et Masaki, gen. nov. Frons carnoso-membranacea, dichotome vel palmate laciniata, stratis tribus contexta; medullari crassi cellulis hyalinis verticale elongatis saepe filamentosis et cellulis gigantis paucis plasmam eodem generem sudflavam complectis compositis; subcorticali paucis seriibus cellularum hyalinarum rotundato-oblongarum compositis; corticali superfici in superiore parte frondis una serie usque tribus seriibus cellularum minutarum coloratarum quamquam in inferiore stipitata parte frondis anticlinalibus seriibus cellularum minutarum coloratarum compositis. Cystocarpia cirruliformia per segmenta superiora sparsa, gregalibus parvis carposporarum filamentis vegetatibus paucis inter se separatis composita. Tetrasporangia per frondem sparsa, in unica serie infra stratum superficum disposita, ex cellulis corticalibus intercalaribus transformia, oblique cruciatim divisa. Spermatangia ignota.

in the maximum and minimum diameter respectively. In the dried specimens mounted on paper, the size of the ringlets is 2.4 × 1.1 mm on the average of 14 samples ranging from 4 to 1 mm and from 1.5 to 0.5 mm in the maximum and minimum diameter respectively. The thickness of the thallus portion containing cystocarps is from 1.00 to 0.77 mm whereas that of the nearby vegetative portion is from 0.55 to 0.30 mm. The mature tetrasporangia are oblong or obovoid in shape and 44 × 18.3 μ in diameter on the average of 37 samples ranging from 58.1 to 32.7 μ and from 27.2 to 12.7 μ in the maximum and minimum diameter respectively. The thickness of the thallus portion containing tetrasporangia is from 0.7 to 0.2 mm whereas that of the nearby vegetative portion is from 0.50 to 0.02 mm.

Résumé

In this paper is reported the discovery of the mature cystocarpic and tetrasporic specimens of the red alga which has been known under the name of *Erythrophyllum Gmelini* (Grun.) Yendo. It was thus made first possible to discuss with certainty the systematic position of the alga which has been uncertain because of lack of precise knowledge about its reproductive organs. Both cystocarps and tetrasporangia are scattered on frond surface, the former in the shape of ringlets in surface view and the latter in one layer beneath the superficial cortical cells in section being transformed from the intercalary cells. A new genus is to be established for the present alga for which is proposed the name *Cirrulicarpus Gmelini* (Grun.) Tokida et Masaki. It belongs to the family Callymeniaceae.

The cost of the present study was partly defrayed from the fund for scientific research granted by the Department of Education.

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