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Upper Triassic *Trizygia* (Sphenophyllales) from Omine, West Japan and Evolution of *Trizygia* Series

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Introduction

Sphenophyllum is a representative plant of the Upper Paleozoic age. The first occurrence was reported by NATHORST in 1902 as *Sphenophyllum subtenerrimum* from the Upper Devonian of Bear Island in Arctic Ocean. To our knowledge, *Sphenophyllum tomiensis* was the latest plant reported from the Upper Permian of Kuznetzk by GORELOVA in 1962. So the plant described as *Trizygia ominensis* n. sp. from the Carnian bed of Omine coal field in this paper is the youngest species of the Sphenophyllales in the world.

In the Euramerican flora all vegetative organs of Sphenophyllales are described under one genus *Sphenophyllum*, which have non-trizygoid leaves arranged around the node of stem. But in the Cathaysia flora they evolved in four directions; non-trizygoid straight vein *Sphenophyllum*, non-trizygoid curved vein *Parasphenophyllum*, trizygoid straight vein *Trizygia* and trizygoid curved vein types *Paratrizygia* respectively. *Trizygia* belongs to the trizygoid straight vein type and they evolved in the Cathaysia land from *Trizygia oblongifolia* to *T. speciosa, T. densinervia, T. sinocoreana, T. grandifolia* and *T. ominensis* successively.

In 1966 the senior writer stated that there were two different trends of evolution in *Sphenophyllum* described from the Cathaysia land. In one trend the leaf segment grows larger while in the other it diminishes in size through the same geological succession. The former trend will be called the stage of size enlargement and the latter the size reduction. In *Trizygia* series the change from *Trizygia oblongifolia* to *T. grandifolia* signify the size enlargement and that from *Trizygia grandifolia* to *T. ominensis* the size reduction respectively.

Horizon and Age of the Momonoki Formation

The specimen described as *Trizygia ominensis* n. sp. in this paper was collected

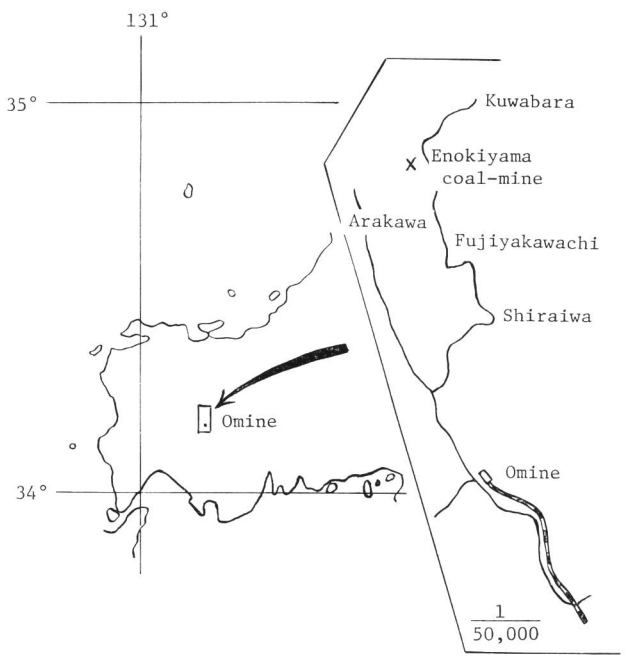

Fig. 1. Map showing the fossil locality.

by the junior author from the Fujiyakawachi coal bed of Momonoki Formation in Enokiyama coal mine, Omine, Yamaguchi Prefecture (Fig. 1). The Mine Group is typically and extensively distributed in the Mine area which is situated in the western end of Honshu, Japan. It was subdivided into three formations as Hirabara, Momonoki and Aso Formations in ascending order by the litho-stratigraphical and paleontological data.

The Hirabara Formation is the lower part of the Mine Group and consists of the three cycles of shallow sea deposits containing the following fossils (TAKAHASHI, 1973, p. 83):

from lower part; Plants, *Neocalamites carrerei* (ZEILL.), *Cladophlebis haiburnensis* (L. et H.), *C. nebbensis* (BRONGN.), *Nageiopsis rhaetica* OISHI, *Podozamites lanceolatus* (L. et H.), *P. nagatoensis* TAK., *Cycadocarpidium erdmanni* NATH., *C. swabii* NATH., *Swedenborgia cryptomerioides* NATH.; Pelecypods, *Anodontophora takiguchiensis* TOK., *Oxytoma pulchrum* KOB. et ICH., etc.

from middle part; *Minetrigonia katayamai* KOB. et ICH., *Edentula ozawai* KOB., *Oxytoma zitteli* (TELL), *O. subzitteli* KOB. et ICH., *O. pulchrum* KOB. et ICH., *Halobia kawadai* YEHARA, *H. kashiwaiensis* KOB. et ICH., *N. aotii* KOB. et ICH., *Bakevelloides hekiensis* KOB. et ICH., *Parallelodon monobensis* NAKAZ., *Mytilus hirabarensis* TOK., *Modiolus okubatensis* TOK., etc.

from upper part; *Oxytoma pulchrum* KOB. et ICH., *Halobia kawadai* YEHARA, *H. kashiwaiensis* KOB. et ICH., *Bakevelloides hekiensis* KOB. et ICH., *Minetrigonia katayamai* KOB. et ICH., *Lima naumanni* KOB. et ICH., *Sakawairhynchia katayamai* TOK., *Rhynchonella hirabarensis* TOK., etc.

The Momonoki Formation, the middle part of the Mine Group, is the main coal measure of the Omine coal field and yields rich varieties of plants as follows:

Arthrophyta: *Neocalamites carrerei* (ZEILL.), *N. hoerensis* (SCHIMP.), *N. minensis* KON'NO et NAITO, *Equisetostachys pedunculata* KON'NO, *Equisetites multidentatus* OISHI, *E. nagatoensis* KON'NO, etc.

Pterophyta: *Todites recurvatus* HARRIS, *T. williamsoni* (BRONGN.), *Clathropteris meniscoides* BRONGN., *C. obovata* OISHI, *Dictyophyllum falcatum* NAITO, *D. nathorsti* ZEILL., *Cladophlebis haiburnensis* (L. et H.), *C. nebbensis* (BRONGN.), *C. raciborskii* ZEILL., *C. williamsonii* (BRONGN.), *C. pseudodelicatulata* OISHI, etc.

Cycadophyta: *Taeniopteris lanceolata* OISHI, *T. minensis* OISHI, *Plagiozamites minensis* TAK., etc.

Ginkgophyta: *Baiera elegans* OISHI, *B. muensteriana* (PRESL.), *B. paucipartita* NATH., *Ginkgoites sibirica* (HEER), *Czekanowskia rigida* HEER, *Phoenicopsis angustifolia* HEER, etc.

Coniferophyta: *Nagatostrobus linearis* KON'NO, *N. stenomischoides* KON'NO, *Sorosaccus naitoi* KON'NO, *Araucarioxylon* sp., *Pityophyllum longifolium* (NATH.), *Podozamites atsuensis* TAK., *P. concinus* OISHI et HUZ., *P. lanceolatus* (L. et H.), *P. schenki* HEER, *Leptostrobus longus* HARRIS, *Stachyotaxus elegans* NATH., etc.

These fossils were almost collected from the Fujiyakawachi coal bed (Fig. 2) and *Trizygia ominensis* n. sp. was also collected from the same bed.

The Aso Formation, the upper part of the Mine Group, consists of the three cycles of shallow sea deposits containing the following fossils:

from lower part; *Chlamys mojsisovicsi* KOB. et ICH., *Tosapecten suzukii* OKADA, *Lima naumanni* KOB. et ICH., etc.

from middle part; *Eumorphotis confertoradiata* TOK., *E. laevigata* TOK., *Oxytoma multistriatum* TOK., *Anodontophora* aff. *kochigataniensis* KOB. et ICH., *Plagiostoma higaeribara* TOK., *Modiolus nagatoensis* TOK., *Camptopteris japonicum* (YOK.) (plant), etc.

from upper part; *Tosapecten suzukii okadai* NAKAZAWA, *Chlamys mojsisovicsi* KOB. et ICH., *Palaeopharus oblongatus* (KOB. et ICH.), *Rhynchonella subflabellata* TOK., *R. asoensis* TOK., etc.

According to KOBAYASHI and KATAYAMA (1938, p. 184), in the Nariwa district the Rhaetic plant bed underlies the *Pseudomonotis* (*Entomonotis*) *ochotica* bed which is indicating the Norian age. So the Nariwa flora of the Rhaetic aspect, which was described as Rhaetic flora by OISHI (1932), is by no means younger than the Norian.

In the Omine area the floral assemblage of the Momonoki Formation was re-

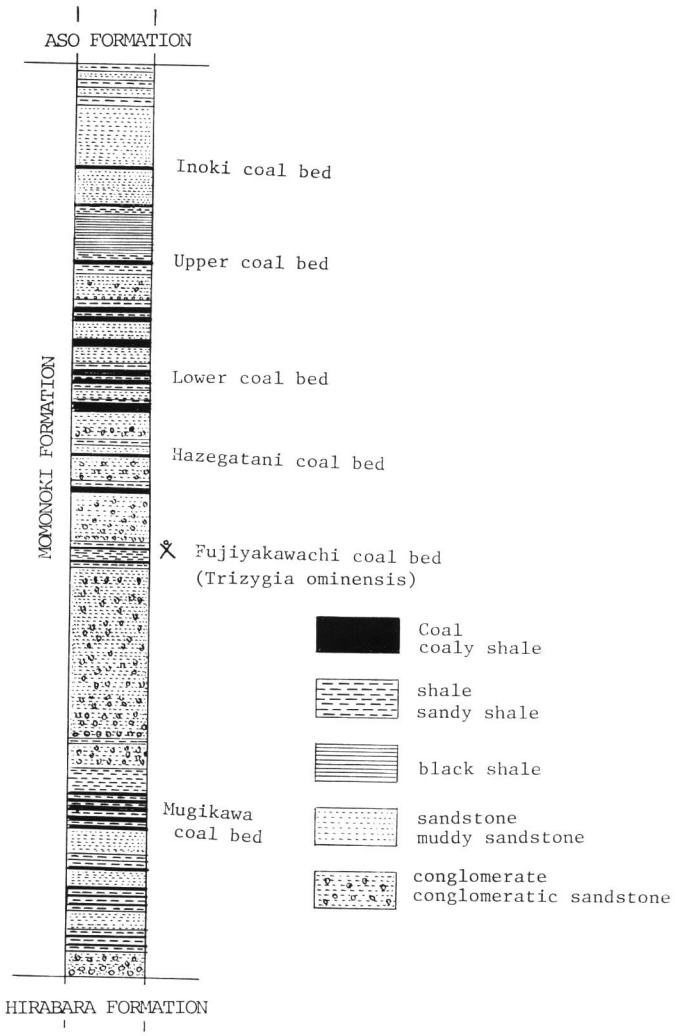

Fig. 2. Geologic columnar section of the Momonoki Formation.

ported as Rhaetic plants by OISHI (1932). The Aso Formation, which overlies the Momonoki Formation, contains such pelecypods as *Tosapecten suzukii* and *Oxytoma zitteli* (KOBAYASHI & KATAYAMA, 1938). These fossils are elements of *Pecten* bed which is located between the *Halobia* and *Pseudomonotis ochotica* beds in the Sakawa basin, Kochi Prefecture. The Aso Formation is not younger than the Norian and the Momonoki Formation is naturally older than the Aso. From the facts mentioned above the Momonoki flora seems to be Carnian in age.

Classification of Sphenophyllales in Cathaysia Land

There are two types of arrangement of leaves in a whorl of Sphenophyllales; one is trizygoid type in which the leaves of a whorl are arranged in three pairs of unequal size, and the other is nontrizygoid type in which the leaves of equal size spread radially. Venation of leaves is rather simple in Sphenophyllales, but there are two types; in one type all the veins giving off from the base of leaves run straightly ending in distal margin, and in the other type the side veins are curving outward ending in side margin.

From the arrangement of leaves in a whorl and the venation of leaves, all the species described from the Cathaysia land are classified into the following four types (ASAMA, 1970):

A. Non-trizygoid, straight vein type ..... *Sphenophyllum*
from China; *Sphenophyllum pseudotenerrimum* SZE, *S. lungtanense* GOTHAN et SZE, *S. verticillatum* (SCHLOTH.), *S. kawasakii* STOCK. et MATH., *S. cuneifolium* (STERNB.), *S. costae* STERZEL, *S. emarginatum* BRGN., *S. grabaui* STOCK. et MATH., *S. trapaefolium* STOCK. et NATH., *S. endoseidoi* NAGAI, *S. rotundatum* HALLE
from Korea; *Sphenophyllum pseudocostae* KAWASAKI, *S. macrotruncatum* KAWASAKI et KON'NO, *S. orientale* KAWASAKI, *S. macrophyllum* TOKUNAGA

B. Non-trizygoid, curving vein type ..... *Parasphenophyllum*
from China; *Parasphenophyllum shansiense* (ASAMA), *P. thonii* (MAHR), *P. thonii* var. *minor* (STERZEL), *P. spinulosum* (YABE et OISHI), *P. neofimbriatum* (HALLE)
from Thailand; *Parasphenophyllum phetchabunense* (ASAMA)

C. Trizygoid, straight vein type ..... *Trizygia*
from China; *Trizygia oblongifolia* (GERM et KAULF.), *T. grandeoblongifolia* (STOCK. et MATH.), *T. speciosa* ROYLE, *T. densinervia* (YABE et OISHI), *T. sinocoreana* (YABE)
from Korea; *Trizygia grandifolia* (KOBATAKE)
from Japan; *Trizygia ominensis* ASAMA et NAITO

D. Trizygoid, curving vein type ..... *Paratrizygia*
from Korea; *Paratrizygia inequifolia* (KON'NO), *P. glossopteroides* f. *minor* (KAWASAKI), *P. koboensis* (KOBATAKE)
from Japan; *Paratrizygia maiyaensis* ASAMA, *P. uedai* ASAMA

Evolution of Sphenophyllales in Cathaysia Land

There are two types of evolutional stage in the evolution of Sphenophyllales of the Cathaysia land. The one is the enlargement stage and the other is the reduction stage. In the enlargement stage the leaf segments of a whorl become larger time

to time and in the reduction stage they become smaller (ASAMA, 1966, 1970). The *Trizygia oblongifolia* series belongs to the former, and the *Parasphenophyllum shansiense* series and the *Paratrizygia maiyaensis* series to the latter.

As mentioned above the senior writer divided Sphenophyllales in the Cathaysia land into four groups by the arrangement and venation of leaves, that is, non-trizygoid straight vein (*Sphenophyllum*), non-trizygoid curved vein (*Parasphenophyllum*), trizygoid straight vein (*Trizygia*) and trizygoid curved vein types (*Paratrizygia*). The non-trizygoid straight vein type (*Sphenophyllum*) comprises fifteen species but we cannot find any evolutionary series between them.

The non-trizygoid curved vein type (*Parasphenophyllum*) comprises six species and they evolved from *Parasphenophyllum shansiense* to *P. thonii, P. thonii* var. *minor* or to *P. spinulosum* and *P. neofimbriatum* reducing their leaf size (ASAMA, 1970. text-fig. 2). Their evolutional trend is from large to small size of leaf, that is, the reduction of leaf segment.

The trizygoid straight vein type (*Trizygia*) contains six species and the best example of the enlargement of leaf size. Their evolutional trend is from small to large size of leaf, that is, the enlargement of leaf segment. They evolved from the first *Trizygia oblongifolia* to *T. speciosa, T. densinervia, T. sinocoreana* and the last *T. grandigolia* increasing their leaf size successively (ASAMA, 1970, text-fig. 1).

The trizygoid curved vein type (*Paratrizygia*) consists of five species and they evolved from large to small leaf size, that is, from *Paratrizygia maiyaensis* to *P. inequifolia, P. glossopteroides* f. *minor* and *P. koboensis* (ASAMA, 1970, text-fig. 3).

Evolution of Trizygia oblongifolia Series

The find of *Trizygia ominensis* from the Momonoki Formation means that a part of Sphenophyllales characterizing the Paleozoic plant world survived in the Carnian of Japan. As mentioned above in the Permian of Cathaysia land evolution of *Trizygia oblongifolia* series indicates the enlargement of leaf size, that is, the evolution from *Trizygia oblongifolia* to *T. speciosa, T. densinervia, T. sinocoreana* and *T, grandifolia*, increasing their leaf size successively (Text-fig. 4). But the change from the Late Permian to the Late Triassic, from *Trizygia grandifolia* to *T. ominensis*, indicates the reduction of leaf size (Text-fig. 4). So the *Trizygia oblongifolia* series has two types of evolutional stage, the enlargement and the reduction stage of leaf size. In the enlargement stage their leaf size become larger and become smaller in the reduction stage. Generally speaking, in both stages plants reduce their vegetative organ step by step. In the enlargement stage the leaf segments become larger reducing their branches step by step and become smaller without reducing their branches in the reduction stage. For example, in the pinnate plants as *Emplectopteris triangularis* the leaf segments become larger, reducing their branches step by step and change from tripinnate to bipinnate, unipinnate and simple leaf plants. This is the enlargement stage of leaf segments. Next the simple leaf reduce their leaf area without

reducing their branches. This is the reduction stage of leaf segments. (see ASAMA, 1962, text-fig. 9 & 1966, text-fig. 9)

Description of Species

Genus *Trizygia* ROYLE

Trizygia ominensis ASAMA et NAITO, n. sp.

Plate 1. figs. 1–5; Text-fig. 3

Description: Stem unknown. Leaves arranged in three pairs, those of the middle pair are longest and the lower pair shortest. Leaves of the upper pair are wide apart at angle of about 120° upward, while leaves of the lower pair a narrow angle downward.

The leaves of the upper and middle pairs are oblanceolate, 27–30 mm long, 7 mm wide and 189–210 mm^2 in area index of leaves. The leaves of the lower pair are oblong, about 20 mm long, 9 mm wide and 180 mm^2 in area index. Veins are about four in number at their origin, forking repeatedly, diverging, running straight to entire margin and numbering about 24 at their outer margin.

Locality: Enokiyama coal mine, Fujiyakawachi, Omine-cho, Mine-shi, Yamaguchi Prefecture.

Horizon: Momonoki Formation (Carnian)

Despository: Holotype, NSM–PP6899 (Pl. 1, fig. 1)

Remarks: There is only one specimen assigned to *Trizygia ominensis* n. sp. which was found by Gentaro NAITO in the Momonoki coal bed of Momonoki Formation.

The Momonoki Formation contains abundant plants which were described by OISHI (1936) as Rhaetian but Carnian (KOBAYASHI and KATAYAMA, 1938). Therefore *Trizygia ominensis* is the youngest species of Sphenophyllales in the world.

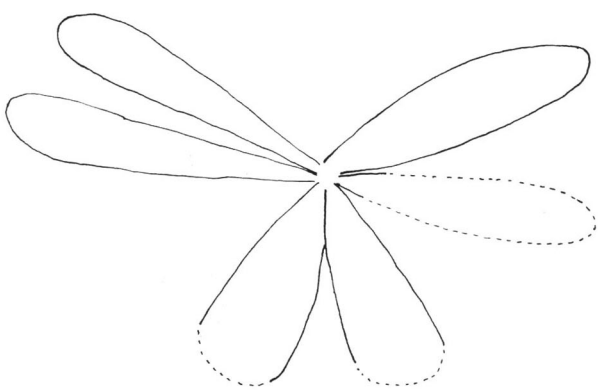

Fig. 3. Leaf arrangement of *Trizygia ominensis* n. sp.

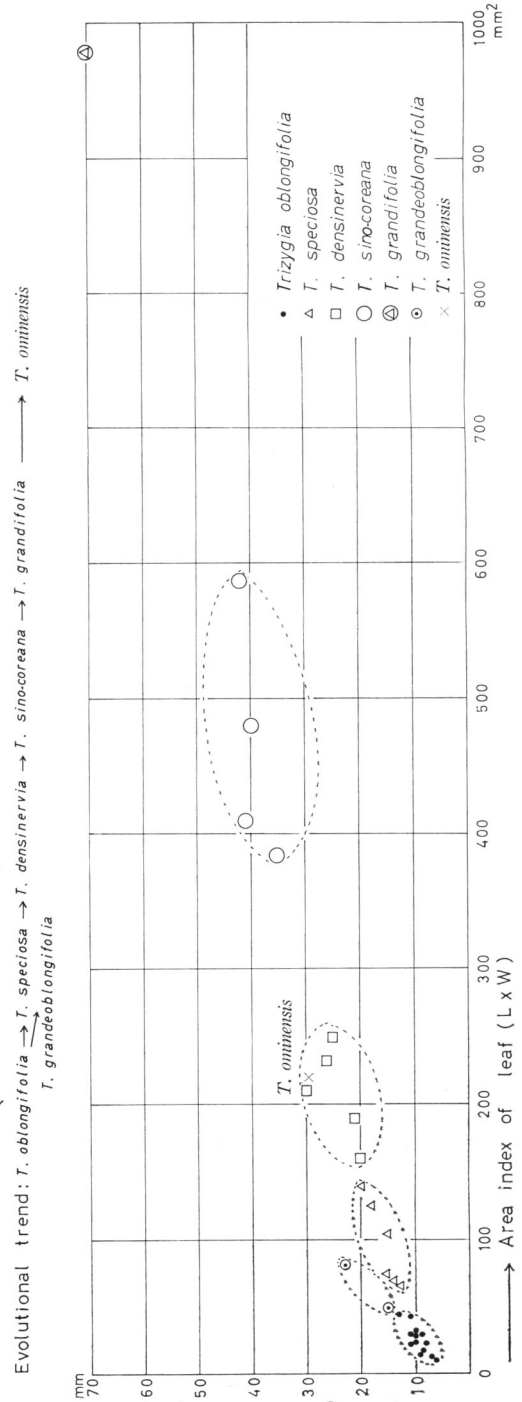

Fig. 4. Evolution of *Trizygia oblongifolia* series.

The specimens shown in Pl. 1, fig. 1 has five leaves arranged in a whorl.

It seems that the middle leaf at right hand was missed. The two leaves of lower pair have no apex but the broadly radiated venation of them and the round distal margin suggest that they are the leaves of lower pair in a whorl.

The specimen described here resembles *Trizygia densinervia* reported by YABE and OISHI (1938) from Fukien, China but different from the latter in the coarse venation and slender leaves.

After the discussion about the relation between *Sphenophyllum* of Northern Hemisphere and India, MATHESHWARI (1968) adopted the original name *Trizygia speciosa* for Indian specimens and separated them from *Sphenophyllum oblongifolium* and *S. sinocoreanum*. When ASAMA (1966a) described the Phetchabun flora from Thailand, he explained as parallelism the similarity of some plants between the Gondwana and the Cathaysia lands (ASAMA, 1976). In the same year (ASAMA, 1966b) he disccussed about Indian species *Sphenophyllum speciosum* described by FEISTMANTEL (1880) and stated that the specimens from the Baraker Series are small in size and comparable to the Cathaysia species such as *S. oblongifolium* but those of Raniganj Series are large and comparable to the Cathaysia species such as *S. sinocoreanum*. Later (ASAMA, 1970) he disccussed the evolution of Sphenophyllales and as mentioned above divided all species from the Cathaysia land into four genera, *Sphenophyllum, Parasphenophyllum, Trizygia* and *Paratrizygia*.

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Explanation of Plate

Trizygia ominensis ASAMA et NAITO, n. sp.

Locality: Enokiyama coal mine (now abandoned), Fujiyakawachi, Omine-cho, Mine-shi, Yamaguchi Prefecture.

Horizon: Fujiyakawachi coal bed of the Momonoki Formation.

Depository: Holotype, NSM-PP6899.

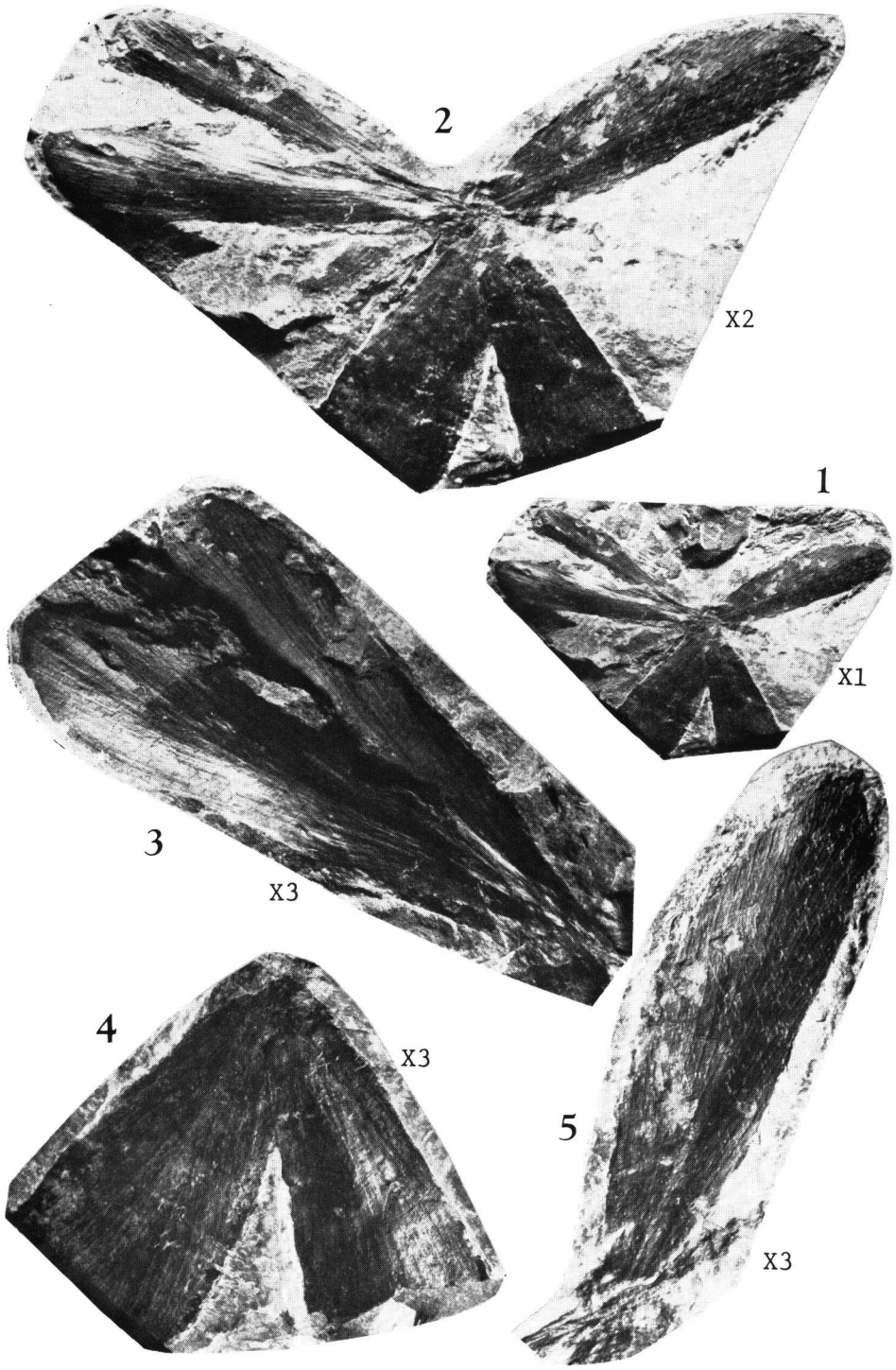
Fig. 1. Holotype. X1

Fig. 2. Showing the arrangement of a whorl and the venation of leaves. X2

Fig. 3. Showing the venation of two leaves at left hand of the whorl. X3

Fig. 4. Showing the venation of two leaves at lower side of the whorl. X3

Fig. 5. Showing the venation of a leaf at right hand of the whorl. X3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