# Evolution and Phylogeny of Vascular Plants based on the Principles of Growth Retardation.
# Part 2. Phylogeny of Microphyllophyta

By

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### Parallelism in the Evolution of Vascular Plants and Vertebrates

In the previous paper the writer summarized the principles of Growth Retardation (G. R.) and postulated the climatic change through ages (ASAMA, 1981 fig. 9) on the basis of fossil evidences of the progressive and regressive evolution of vascular plants. Climatic changes are considered to be the main factor in investigating the phylogeny of vascular plants. If the climatic changes postulated on the basis of the evolution of vascular plants are correct, the evolution of vertebrates also can be explained by the factor of the climatic changes. The writer briefly discussed on the similarities in the patterns of macro-evolution of vascular plants and vertebrates (ASAMA 1980). Macro-evolution of vascular plants (Fig. 1) is comparable to that of vertebrates (Fig. 2).

In general, the stages of the greatest developments of pteridophytes, gymnosperms and angiosperms were in the Late Paleozoic, Mesozoic and Cenozoic, respectively. The reporductive organs changed from the spore of pteridophytes to the naked seed of gymnosperms and the naked seed changed to the enclosed seed of angiosperms through ages. This means that the reproductive method had become steady age by age with spore and seed protected by the changed leaves (integuments or carpels). This plants of the spore stage (pteridophytes) in Paleozoic must have been lived under the warm and wet climate as the adaptive environments, the naked seed plants (gymnosperms, especially Bennettitales) in Mesozoic under the warm and sometimes dry climate, and the enclosed seed plants (angiosperms) in Cenozoic could have lived under even drier and colder climates. That is to say, the reproductive organ had changed to be capable to perform their function in successively severe environments.

The patterns of macro-evolution of vascular plants mentioned above are very similar to those of vertebrates. Evolutionary stages of such vascular plants as pteridophytes, gymnosperms and angiosperms correspond with those of amphibians, reptiles and mammals in vertebrates, respectively (Figs. 1 and 2).

Pteridophytes and amphibians succeeded to come out of water on to the land, but they could not live away from water. Gymnosperms and reptiles are adapted to the life in the dry land but they could not live in the low temperature. Angiopserms and
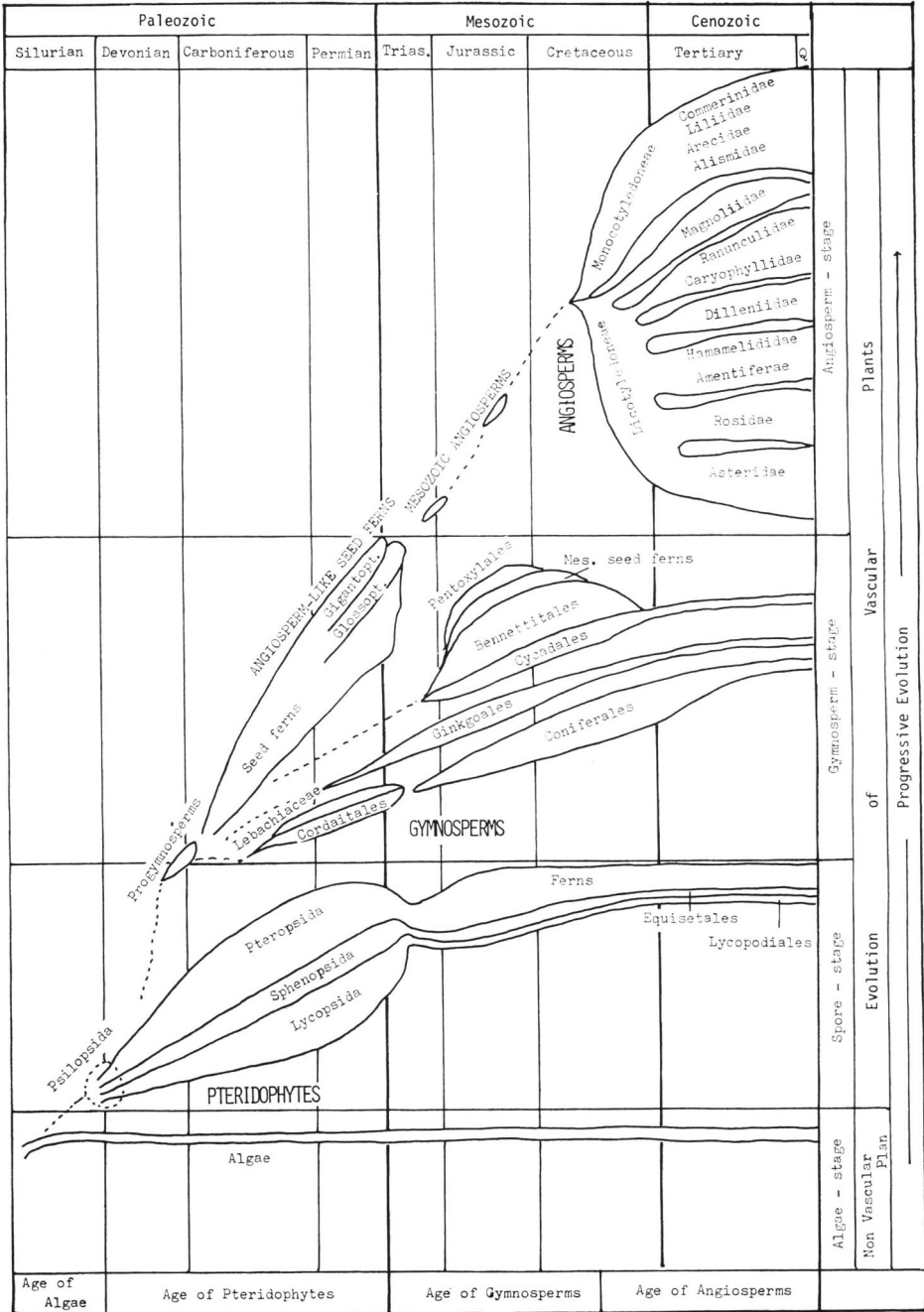
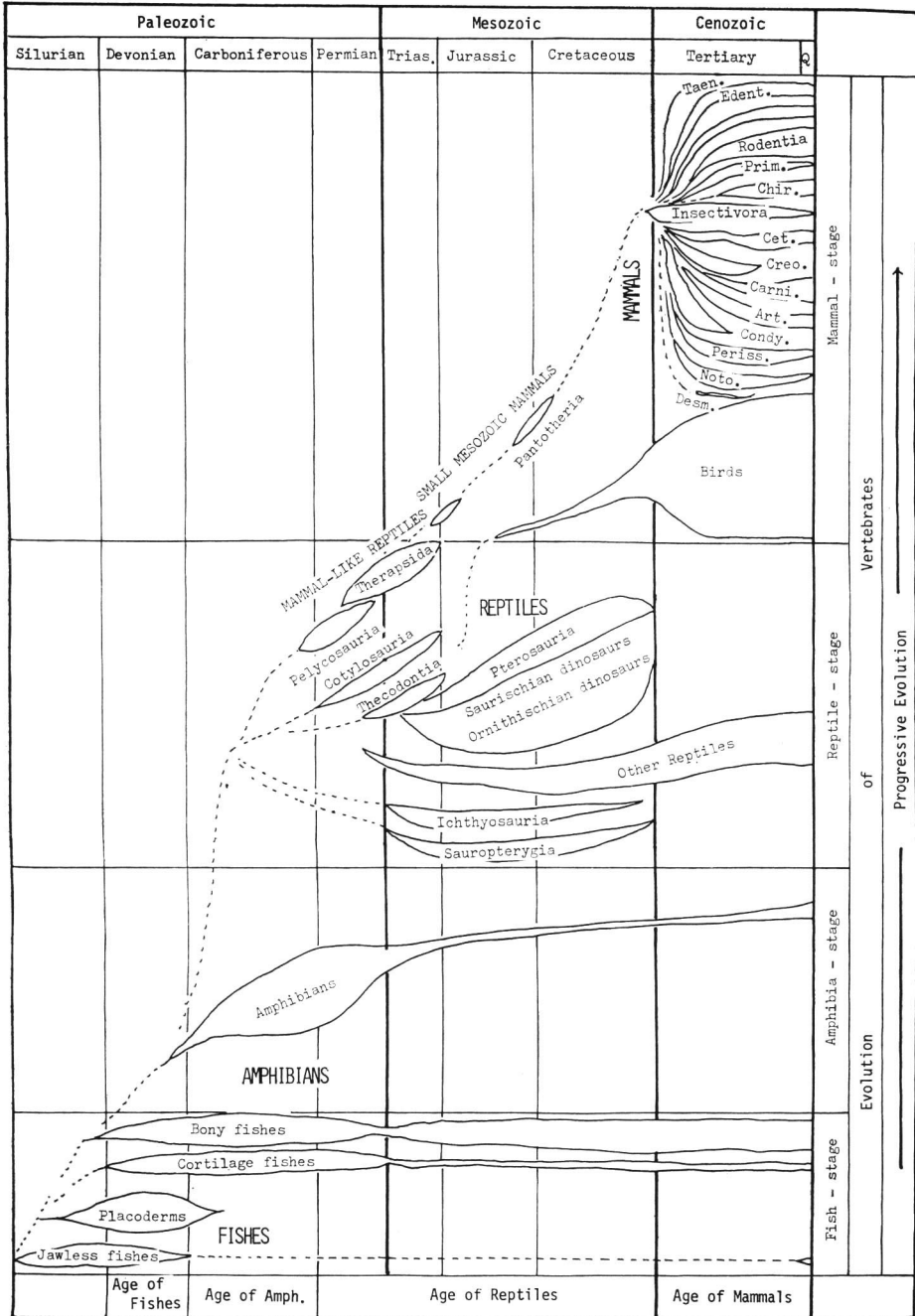Fig. 1.  Macro-evolution of vascular plants.  (Adapted from Dorf, 1955; Sporne, 1965; Asama, 1975).

Fig. 2. Macro-evolution of vertebrates. (Adapted from GINGERICH, 1977; COLBERT, 1969; ROMER, 1966).

mammals are adapted to live in both dry and cold environments.   That is to say, vascular plants and vertebrates evolved in parallel.   The present author thinks that the cause by which they had to evolve in parallel is the paleoclimatic changes through ages (Asama, 1981, fig. 9).   It is very hot in summer and very cold in winter on the middle latitude of the present earth.   Early Devonian plants in both northern and southern hemispheres were all having spores.   This means that the Devonian climate was very mild comparing to the present climate.   Therefore, the writer postulated the gradual climatic change from Devonian to present (Asama, 1981, fig. 9).   Upper Paleozoic glaciations in Gondwanaland were expected because they were situated around the south pole.   These climatic change can be explained by the increasing continental land or the increasing inclination of rotaing axis of the earth (Fig. 3) through ages, if it is possible to trust Teraishi (1949).



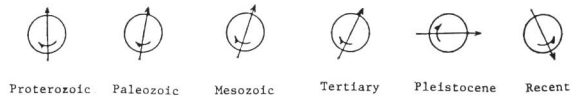Proterozoic   Paleozoic   Mesozoic   Tertiary   Pleistocene   Recent

Fig. 3.   Increasing inclination of rotating axis of the earth (Teraishi, 1949).

Judging from the parallel evolution of vascular plants and vertebrates, the writer thinks that the macro-climatic changes shown in Part 1, (Asama, 1981, fig. 9) indicate the true climatic change through ages.

## Original Types of Vascular Plants

Early land plants, all in spore stage, appeared in the latest Silurian and Devonian ages, and their maximum development and diversification are attained in Carboniferous. Carboniferous vascular plants in spore stage are clearly classified into three types, Lycopsida (with microphylls), Pteropsida (with macrophylls) and Sphenopsida (with articulate stems) by the characteristics of leaves and stems.   We find the ancestors of these three lines of Carboniferous plants in Devonian, *Drepanophycus* or *Protolepidodendron* with microphylls, *Archaeopteris* or *Sphenopteris* with macrophylls and *Equisetophyton*, *Sphenophyllum* or *Pseudobornia* with articulate stems.

Fig. 4 shows the first appearance of Devonian plants adapted from Banks's range chert of Devonian megafossils (Banks, 1980) and rearranged by the present writer's opinion in three phyletic lines, Macrophyllophyta, Microphyllophyta and Arthrophyta on the basis of principles of G. R.

In general, Devonian plants are classified into four lines of plants, Psilopsida, Lycopsida, Pteropsida and Sphenopsida, and it is believed that Psilopsida were the ancestral plants of other three lines of plants.

Greguss (1964) proposed the triphyletic evolution of the land plants.   He thought that branching has played a decisive role in the history of evolution of the vegetative kingdom.   He classified land plants into three lineages by such branching as mono-

podial, dichotomous and verticillate.   But the present writer thought that such leaf or stem as microphyll, macrophyll and articulate stem are more essential characters than branching system recognizable through pteridophytes, gymnosperms and angiosperms. In general many authors recognize microphyll, macrophyll and articulate stem in pteridophytes only, but the present writer believes that such leaf and stem characters as microphyll, macrophyll and articulate stem should be applied to all vascular plants. Because these characters must have been orginal representing their lineage through ages.

The leaves are arranged spirally around the stem and are very small in most Lycopsida.   Each leaf has a single vein that does not form a leaf gap at the point of emergence from the stele within the stem.   Such leaves are microphylls.   In general the leaves of Lycopsida and Sphenopsida have small type of microphylls, but they sometimes have large type of leaves derived from fusion of many microphylls (Principle C, "Enlargement & Fusion"; see ASAMA, 1981, fig. 2).   These fused large leaves are found in *Cordaites, Lobatannularia* and *Schizoneura* in the Upper Paleozoic, *Podozamites* in Mesozoic, and Podocarpaceae and Graminae in Recent.

Each leaf of Pteropsida is very large and has many pinnate or anastomosed veins, and forms a leaf gap at the point of emergence from the stele within the stem.   The leaves are usually much larger in size than those of Lycopsida and often of great dimensions and lobed in complicated manner.   They are regarded as macrophylls and are always characterized by leaf gaps.

JEFFREY (1917) considered that the leaf of Lycopsida does not form leaf gap, and Pteropsida has leaves with leaf gap representing its lineage.   The present writer considers that the leaf of Lycopsida does not form leaf gap because the leaf is very small, but the leaf of Pteropsida does because it is very large.   In Lycopsida the branch forms branch gap.   This means that gap is formed when the bulk of leaf trace emarges from the stele irrespective of its lineage.   The leaf of Recent conifers is small in size, but it forms leaf gap, because it corresponds to the branch of Paleozoic conifers (Principle D, "Reduction": see ASAMA, 1981, fig. 2).   Therefore the leaf gap does not indicate lineage, and we cannot decide the lineage of vasuclar plants based on with or without leaf gap.

If we do not consider the anatomical structure of stele presence or absence of the leaf gap, as the indicator of phylogeny, we can find both microphyll and macrophyll in pteridophytes, gymnosperms and angiosperms through ages.

Plants in geological ages regularly changed their leaf forms in response to the environmental changes.   And their changes are always explained by the principles of Growth Retardation.   Therefore, we must recognize that such characteristics as microphyll, macrophyll and articulate stem are the inherent character of each lines and that these characteristics are still succeeded in recent plants showing each lineage.   So the writer classified the vascular plants into three lines, Microphyllophyta, Macrophyllophyta and Arthrophyta (ASAMA, 1975).   The plants of these three lines have evolved in parallel from the stage of spore to the stage of angiosperms through that of gymno-

sperms.

In general the leaves of Microphyllophyta and Arthrophyta are microphyllous showing small leaves, and those of Macrophyllophyta are macrophyllous showing large leaves. Sometimes, the leaves of Microphyllophyta and Arthrophyta show large leaves aggregating many microphylls and those of Macrophyllophyta show small type of leaves reducing their size as shown in the plants of desert. Therefore, even though plants have a large type of leaves, they must be plants belonging to Microphyllophyta, if they have leaves derived from microphylls. Reversely even though plants have a type of small leaves they are plants belonging to Macrophyllophyta, if they have the leaves derived from macrophylls. The relation between the leaf size and lineage is very significant.

The plants having a type of large leaves are not always plants belonging to Macro-phyllophyta and those having small type of leaves are not always plants belonging to Microphyllophyta. Sometimes plants of Microphyllophyta and Macrophyta may have articulate stem caused by shortening of stem (Principle E, "Shortening-Verticillation": see Asama, 1981 fig. 2). But they do not belong to Arthrophyta because the articulate secondary stems were derived by G. R. from the non-articulate primary stems. The judgement of lineage must be made on the basis of determined by original type of leaves or stems.

It is not difficult to find whether such character as microphyll, macrophyll and arti-

| | | | Macrophyllophyta | Microphyllophyta | Arthrophyta |
|---|---|---|---|---|---|
| | | Post Famennian | | | |
| Devonian | Upper | Famennian | Sphenopteridium Sphenopteris Archaeosperma Rhacophyton | Cyclostigma | Pseudobornia Sphenophyllum Eviostachya |
| | | Frasnian | *Proteokalon Archaeopteris (=Callixylon) | Protolepidodendropsis Bergeria | |
| | Middle | Givetian | Barrandeina Svalbardia Uralia Enigmophyton | Lepidodendropsis | |
| | | Eifelian | *Tetraxylopteris Protocephalopteris Duisbergia *Pseudosporochnus *Aneurophyton (=Eospermatopteris) *Rellimia (=Protopteridium) | Colpodexylon | Calamophyton (fern?) Hyenia (fern?) |
| | Lower | Emsian | *Pertica *Eogaspesiea *Trimerophyton | Leclercqia Protolepidodendron | |
| | | Siegenian | *Rebuchia (=Bucheria) *Horneophyton *Rhynia *Sawdonia *Gosslingia *Psilophyton | Asteroxylon Baragwanathia Drepanophycus | Equisetophyton |
| | | Gedinnian | *Zosterophyllum | | |
| Silurian | Uppermost | Pridolian | *Taeniocrada *Steganotheca *Cooksonia | | |

Fig. 4.  First appearance of Devonian land plants.  (Adapted from Banks, 1980).
    * without leaves.

culate stem is original or derived one.   If the character is found in all plants belonging to some order, it is the original character and if that is found only in some plants of some order, it is the derived one.   For example, articulate stems are found in all plants belonging to Graminales and found in some plants belonging to Palmales.   Therefore the former's articulate stems are original character and the latter's articulate stems are secondary character derived from non-articulate stems.   The former indicates lineage and the latter does not indicate lineage.

Fig. 4 shows the first appearance of three lines of plants, Macrophyllophyta, Microphyllophyta and Arthrophyta and many paleobotanists do not recognize polyphyletic lines in the vascular plants.   ZIMMERMANN (1959) proposed the Telome theory and he explained the evolution of all vascular plants from a very simple leafless ancestral type, like *Rhynia* (Fig. 5).   The present writer considers, based on the principles of Growth
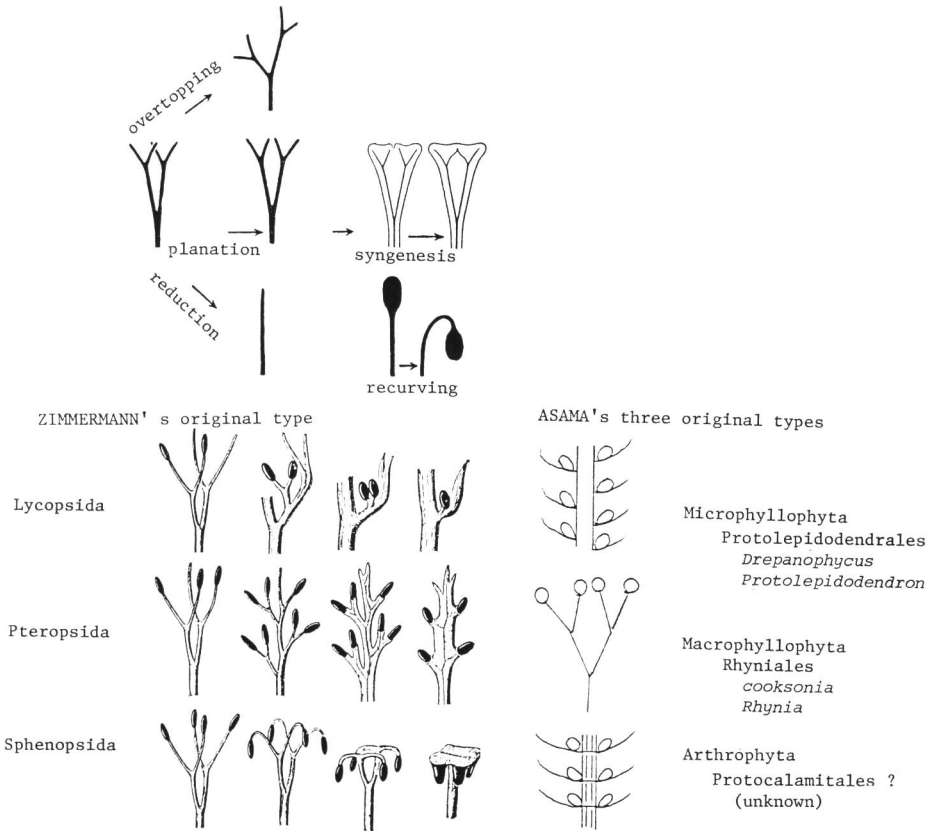
Fig. 5.   Telome theory of ZIMMERMANN (1959) and three original types of the vascular plants of ASAMA (1975).   ZIMMERMANN considers that all vascular plants (Sphenopsida, Lycopsida and Pteropsida) are derived from the only one kind of original plants.   ASAMA considers that the three types of original plants succeeded to come out of water to on land.

Retardation, that Pteropsida will be derived from the plant with terminal sporangia (Zimmermann's original type), but Lycopsida and Sphenopsida will not be derived from such plants as *Rhynia* with terminal sporangia.   It is very difficult to consider that Protolepidodendrales with sporangia on the adaxial surface or in its axil might have been derived from the *Rhynia*-like plants with terminal sporangia in a short period.   Therefore, the writer proposed three original types as showed in Fig. 5.   He considers that the ancestral types of Macrophyllophyta and Microphyllophyta might have been the plants belonging to Rhyniales and Protolepidodendrales, respectively.   Many paleobotanists [Darrah (1960), Andrews (1961), etc.] considered that the ancestral plants of Sphenopsida might have been *Hyenia* and *Calamophyton*, which were clarified to belong to ferns by Leclercq & Schweitzer (1965) and Schwetzer (1972).   Therefore, the earliest representatives of the Sphenopsida in the fossil record are *Eviostachya*, *Sphenophyllum* and *Pseudobornia* from uppermost Devonian deposits.   Recently, however, Schweitzer (1972) reported *Equisetophyton praecox* with well articulated stems from the Upper Siegenian of Overath near Cologne, Rheinland.   Schweitzer's specimen in the report is a single specimen, not good in preservation, and indicates that the plant belonging to Articulate existed in the Lower Devonian of Rheinland.   Accordingly at first Rhyniales, the ancestor of Macrophyllophyta, then Protolepidodendrales and Protocalamitales (?) suceeded came out from water on to land in Siegenian (Fig. 4).

Banks (1968, 1970) classified the vascular plants into two major lines, Rhyniophytina with terminal sporangia and Zosterophytina with lateral sporangia (Fig. 6). He considers that progymnosperms, articulates, cladoxylaleans and coenopterids belong to Rhyniophytina line, and Lycophytina belong to Zosterophytina line, respectively.

The present writer classifies the vascular plants into three lines, Microphyllophyta, Macrophyllophyta and Arthrophyta as mentioned above (Fig. 7).   He recognizes two evolutionary trends in each lines: regressive and progressive ones.   As shown in Fig. 7 and Asama (1981, fig. 6) recent Lycopodiales and Coniferales are derived from the ancestral Paleozoic Lepidodendrales.   The former did not change their reproductive method and remained in the spore stage.   The latter changed their reproductive method to more advanced naked seed (gymnosperm stage).   In the case of the former, we find the remarkable size reduction.   Paleozoic lycopods were giant arborescent trees, but recent lycopods are very small and herbaceous.   The writer considers such change as results of regressive evolution.   In the case of the latter, the reproductive organ was improved from the spore to the seed and other new characters were added in the stem structure successively.   So they could grow to be arborescent trees.   The writer considers the change as results of progressive evolution.   It is possible to find the same manner of changes in Macrophyllophyta and Arthrophyta as shown in Fig. 7 and Asama (1981, figs. 7 and 8).

### Phylogeny of Microphyllophyta

Fossil evidences show that *Cooksonia* was the first land plant as shown in Fig. 4,
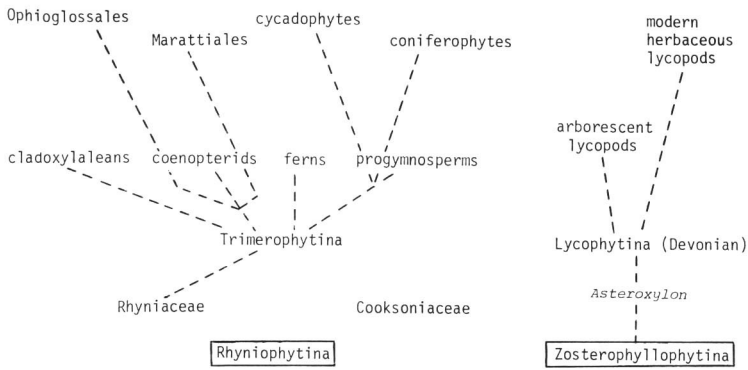
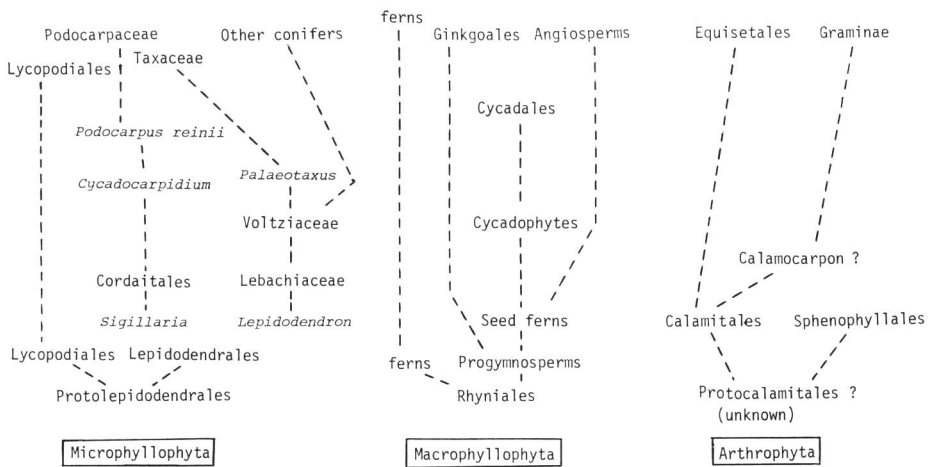Fig. 6. Biphyletic evolution of vascular plants (BANKS, 1968).



Fig. 7. Triphyletic evolution of vascular plants (ASAMA, 1975).

but this does not mean that all other vascular plants were derived from *Cooksonia*. As stated in the previous chapter, the writer considers three original types, plants with microphylls, macrophylls and articulated stems for three lines. The original representatives of three lines might have been Protolepidodendrales, Rhyniales and Protocalamitales (?, ancestral plants in the early Devonian, *Equisetophyton*) as shown in Fig. 7.

The starting plants of Microphyllophyta might have been originated from such Protolepidodendrales as *Protolepidodendron*, *Drepanophycus* and *Baragwanathia*, from which all plants belonging to Microphyllophyta were derived. They evolved in two directions, the regressive evolution without improving their reproductive organs and the progressive evolution improving their reproductive organs from spore to the naked and the enclosed seed. It is easy to find the lineage in the regressive evolution, because the reproductive organs remained in the spore stage and they are classified as Lycopsida.

It is difficult to trace their lineage in the progressive evolution because their reproductive organs had changed from spores to naked seeds and to enclosed seeds.   They evolved from pteridophytes to the gymnosperms and to angiospermous plants.

Paleobotanists recognize the evolution from Protolepidodendrales with microphylls to Lepidodendrales with microphylls, but do not recognize the evolution from Protolepidodendrales to Coniferales with microphylls.   In general many paleobotanists believe that Archaeopteridales are the precursor of conifers.

BECK (1976) considers that the majority of genera in Progymnospermopsida fall into three major categories, the Aneurophytales, the Protopityales and the Archaeopteridales.   He suggested that the lyginopterid Pteridosperms probably evolved from the aneurophytes and the Archaeopteridales are the most possible ancestor of the coniferophytic gymnosperms.   His view based largely on the remarkable resemblance between the secondary wood (*Callixylon*) and lateral branch system of *Archaeopteris* and those of Coniferales.   The present writer considers that the plants belonging to Progymnospermopsida (Aneurophytales and Archaeopteridales) have macrophylls or the ancestral naked branches of macrophylls and are classified in the present writer's Macrophyllophyta.   The Archaeopteridales might have been the precursor of seed ferns or ginkgophytes and not the ancestral plants of Coniferales.

SCAGEL *et al.* (1965) stated "In some vegetative structure, especially the leaves, major gaps occur between the progymnosperms and the Cordaitales, and again between the Cordaitales and the Lebachiaceae."   Both Cordaitales and Lebachiaceae form cones as reproductive organs and the most important character of conifers is to form cones.   Progymnosperms do not have cones and have the fern-like or seed fern-like reproductive organs.   Cones might not be derived from these fern-like reproductive organs.   The writer considers that the similarities of reproductive organs are more important factors than those of the secondary wood or the branching system for finding phylogenetic lines.   The writer will discuss in detail about the problems of progymnosperms in Part 3.

1)   Change of vegetative organs through ages based on the principles of Growth Retardation (Fig. 9).

The ancestor of Microphyllophyta might have been *Drepanophycus* or *Protolepidodendron* with the spirally arranged microphylls around the axis.   The change of microphylls proceeded into two directions, *Sigillaria-Cordaites* line and *Lepidodendron*-Lebachiaceae line.   In the former line the leaves became larger reducing their branching (*Sigillaria*) and fusing leaf segments (*Cordaites*) (Principle C, "Enlargement and Fusion") in the late Paleozoic, and became smaller as shown in *Podozamites* in Mesozoic and in Podocarpaceae in Cenozoic (Principle D, "Reduction").   In the *Lepidodendron*-Lebachiaceae line leaves dit not become so large and the branching of the stem changed from dichotomous to monopodial in the late Paleozoic, and the reduction of branching and the leaf size proceeded in Mesozoic and Cenozoic.

2)   Change of reproductive organs through ages based on the principles of Growth

Retardation (Fig. 10).

(1)   Forming cones

In the primitive plants of Microphyllophyta (*Drepanophycus*, *Protolepidodendron* and *Baragwanathia*) sporophylls were spaced around the stem, and in Lepidodendrales they were aggregated in the terminal cone.   Such cones as shown in lycopods and horse tails are the most important character of all plants having microphylls, and we are unable to find cones in the plants having macrophylls in the Late Paleozoic.   The plants with macrophylls never formed cones in such early evolutionary stage as Paleozoic.

(2)   From spore to naked seed and to enclosed seed

Most cones of *Lepidodendron* (*Lepidostrobus*) are heterosporous, having micro-sporangia on the sporophylls of upper part of cone and megasporangia on the sporo-phylls of the lower part of same cone.   The megaspores are much larger than the micro-spores.   The megasporangia contains a number of megaspores, reducing the number of spores through ages and only one in some species (Principle D, "Reduction").   In *Lepidocarpon* (BALBACH, 1962) the megasporangium is completely enclosed by the lateral laminae of sporophyll (integuments) in the lower part of the cone and is incompletely enclosed in the upper part of the cone.   This indicates that the enclosure of sporangium (forming naked seed) by some appendage began in *Lepidocarpon* during the Early Carboniferous.   *Lepidocarpon* belongs not to pteridophytes, but to gymnosperms, if we define gymnosperms as the plants having the naked seed.

It is not unusual to find the phenomena of enclosure, especially in the herbaceous monocotyledoneous plants, which means the inner segment enclosed and sometimes fused by the outer segment, when the growth of plants are retarded.   The Principles of Growth Retardation (ASAMA, 1981 1, fig. 2) are based on the Permian plants of Shansi. If we refer to the change of Recent plants, one more principle, Principle H, "Enclosure" should be added to the seven principles of Growth Retardation mentioned above. The cones of Lebachiaceae with the naked seeds in *Lepidodendron*-Lebachiaceae line might have been derived from such cones with enclosed megaspore as those of *Lepido-carpon*.   In *Sigillaria*-*Cordaites* line the cones with enclosed spore of *Sigillaria* are not known in fossils but we may expect the same process of forming of the naked seed as shown in *Lepidocarpon*.   As pointed out by SCAGEL, *et al.* (1965), major gaps occur between the leaves of Archaeopteridales and Cordaitales, and again between the leaves of Cordaitales and Lebachiaceae.   The change of leaves from *Archaeopteris* to *Cordaites* or from *Cordaites* to *Lebachia* does not seem to be accomplished in a short period. Principles of Growth Retardation indicate that it is easy to change leaves abruptly from small to large type by the fusion or the enlargement (ASAMA, 1981, fig. 2, Principle A, "Fusion" and Principle B, "Enlargement") but difficult to change leaves abruptly from large to small type (ASAMA, 1981, fig. 2, Principle D, "Size Reduction").   Therefore, change from the small leaves of Lepidodendrales to the large leaves of Cordaitales is easy but change from the large leaves of Cordaitales to the small leaves of Lebachiaceae is difficult.   We must trace the lines on both the basis of vegetative organs and re-productive organs.

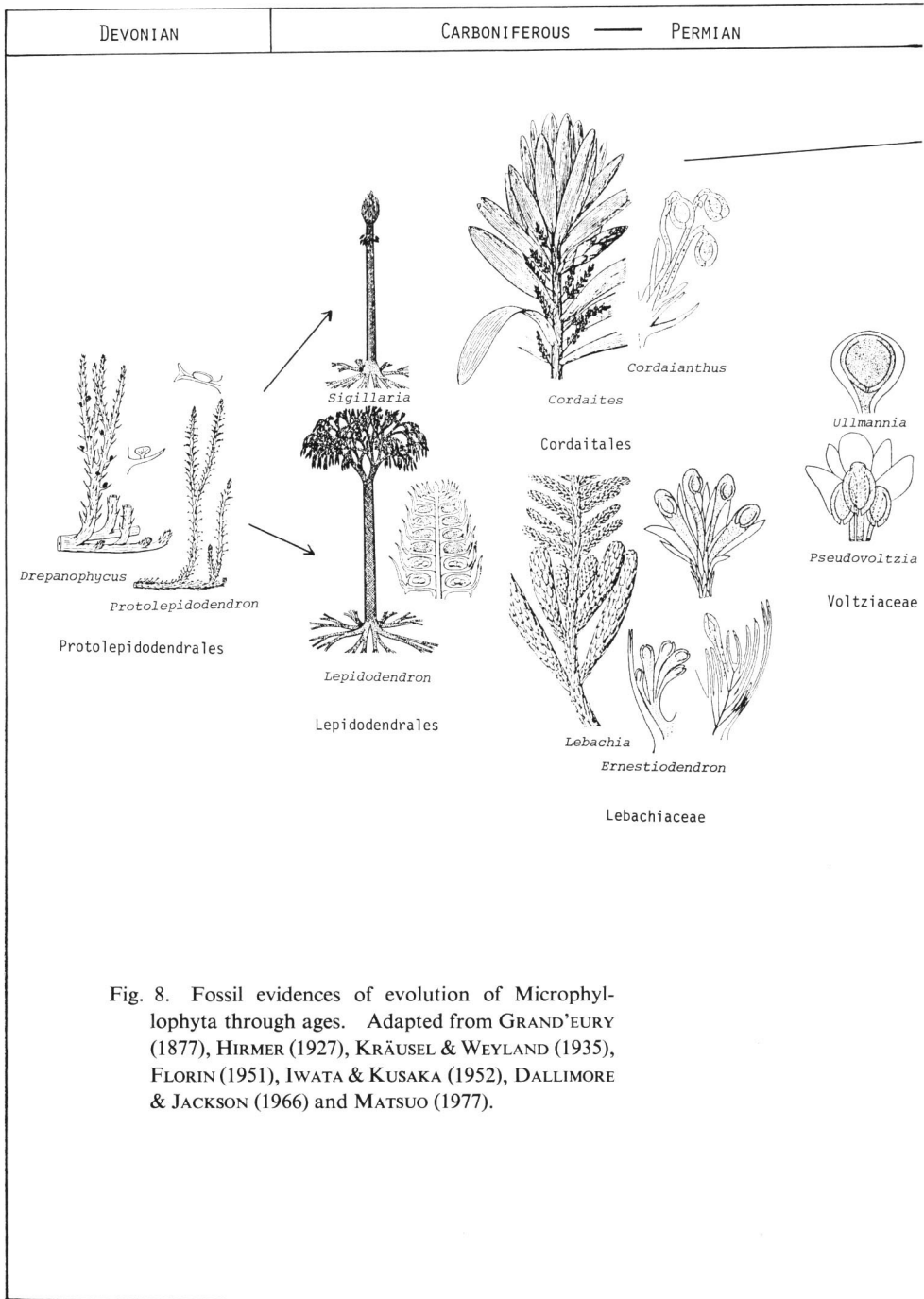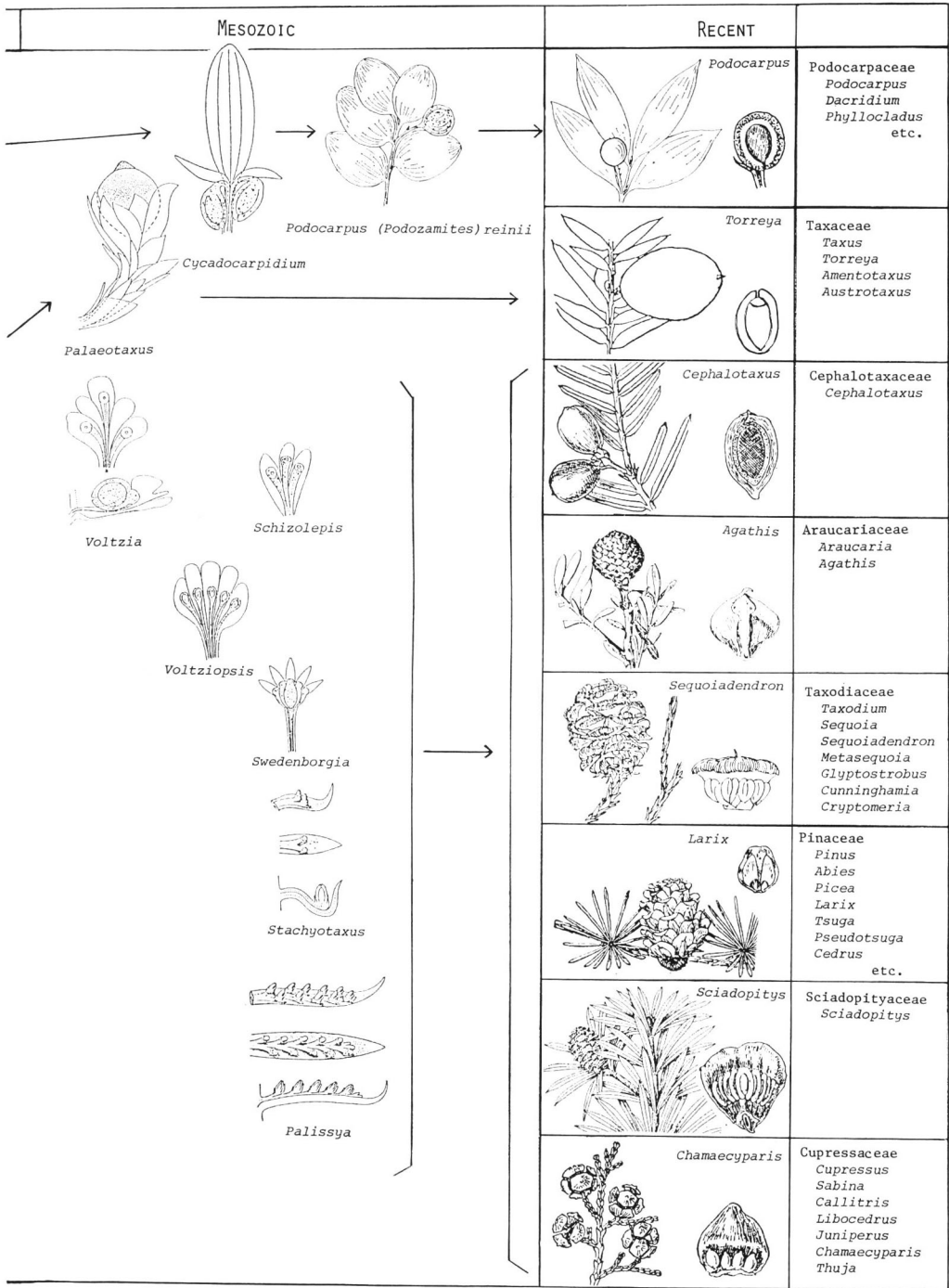| DEVONIAN | CARBONIFEROUS ——— PERMIAN |
|----------|---------------------------|



Fig. 8. Fossil evidences of evolution of Microphyllophyta through ages. Adapted from GRAND'EURY (1877), HIRMER (1927), KRÄUSEL & WEYLAND (1935), FLORIN (1951), IWATA & KUSAKA (1952), DALLIMORE & JACKSON (1966) and MATSUO (1977).

| MESOZOIC | RECENT | |
|---|---|---|
| *Podocarpus (Podozamites) reinii* *Cycadocarpidium* *Palaeotaxus* | *Podocarpus* | Podocarpaceae *Podocarpus* *Dacridium* *Phyllocladus* etc. |
| | *Torreya* | Taxaceae *Taxus* *Torreya* *Amentotaxus* *Austrotaxus* |
| *Voltzia* *Schizolepis* | *Cephalotaxus* | Cephalotaxaceae *Cephalotaxus* |
| *Voltziopsis* | *Agathis* | Araucariaceae *Araucaria* *Agathis* |
| *Swedenborgia* | *Sequoiadendron* | Taxodiaceae *Taxodium* *Sequoia* *Sequoiadendron* *Metasequoia* *Glyptostrobus* *Cunninghamia* *Cryptomeria* |
| *Stachyotaxus* | *Larix* | Pinaceae *Pinus* *Abies* *Picea* *Larix* *Tsuga* *Pseudotsuga* *Cedrus* etc. |
| | *Sciadopitys* | Sciadopityaceae *Sciadopitys* |
| *Palissya* | *Chamaecyparis* | Cupressaceae *Cupressus* *Sabina* *Callitris* *Libocedrus* *Juniperus* *Chamaecyparis* *Thuja* |

The primary cones (flowers, not inflorescence) of *Cordaianthus* have shorter, simple sterile leaves at the base, and elongate, forking and projecting megasporophylls in the apical region, where they carry terminally two or more pendulous ovules (seeds) as shown in Fig. 8.   We cannot find the descendant plants of Cordaitales till Triassic. *Cycadocarpidium* found in Triassic and Jurassic might have been derived from Paleozoic Cordaitales.   The primary cone (flower) of *Cycadocarpidium* is much reduced, and has only two distal sterile leaves and two basal megasporophylls.   The cone of *Podocarpus* (*Podozamites*) reinii (MATSUO, 1977) from the lower Cretaceous of Japan is much reduced than that of *Cycadocarpidium*, and it has only one enclosed seed (fruit). MATSUO considered that it belongs to *Podocarpus* (Fig. 8).   In the *Sigillaria*-Cordaitales line, the number of seeds of the primary cone (flower) were reduced from several seeds in *Cordaianthus* to only one enclosed seed (fruit) in *Podocarpus* (Fig. 8).

In the *Lepidodendron*-Lebachiaceae line the primary cone (flower) of Lebachiaceae has several small sterile leaves and several seeds, which were reduced to only one enclosed seed in *Palaeotaxus*, *Taxus* and *Torreya* (Fig. 8).

*Podocarpus*, *Palaeotaxus*, *Taxus*, *Torreya* and *Cephalotaxus* have the enclosed seeds (fruits).   Therefore, if we define angiosperms as the plants having the enclosed seed, we may call them angiosperms.   These conifers are on the evolutional level same as the angiosperms.   Spore, naked seed and enclosed seed are indicating the level of
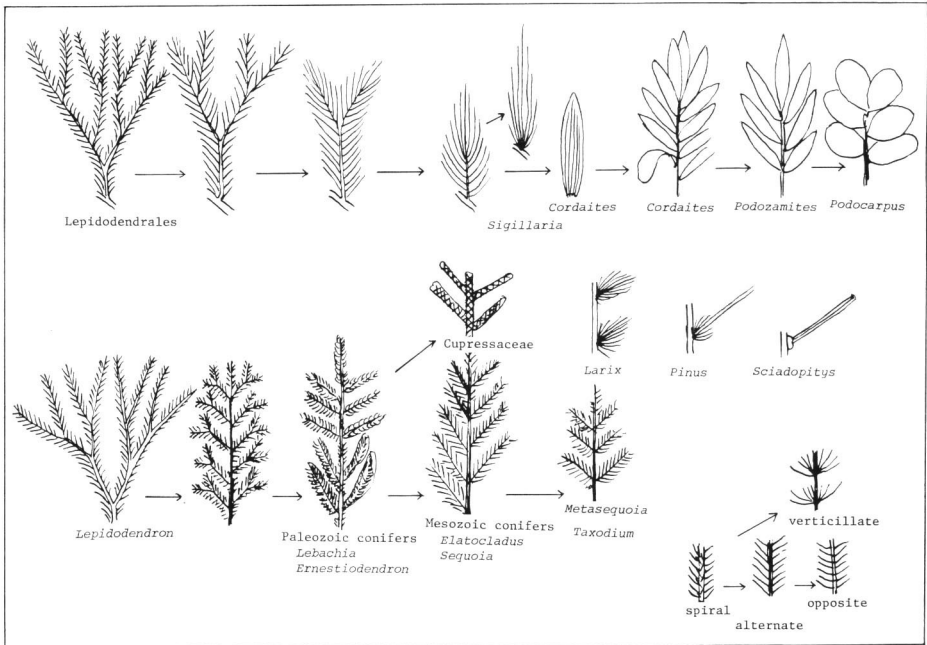


Fig. 9.   Expected change of the vegetative organs in Microphyllophyta based on the principles of Growth Retardation.
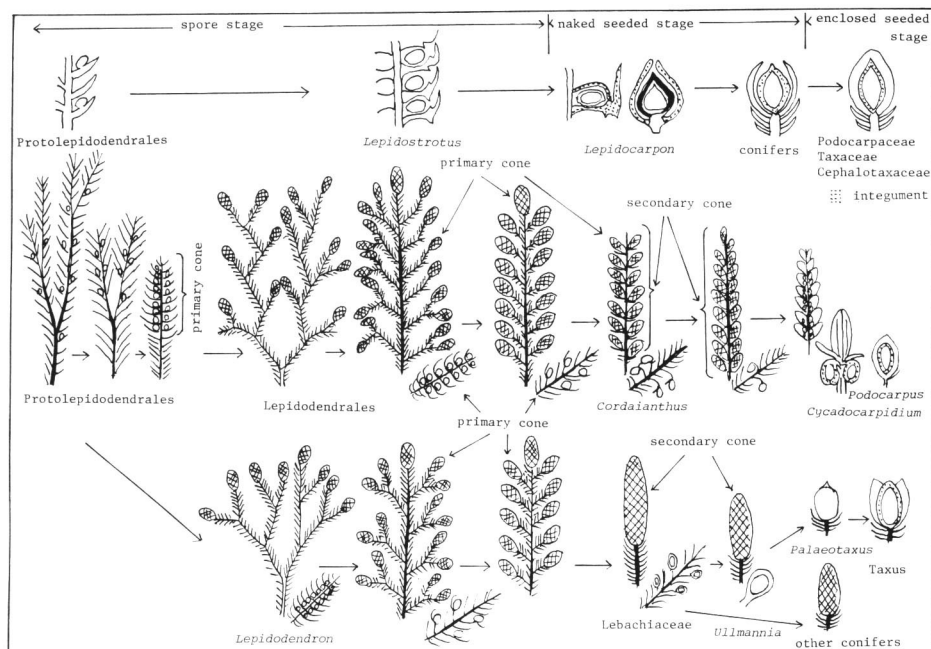
Fig. 10.  Expected change of the reproductive organs in Microphyllophyta based on the princi-
ples of Growth Retardation.

evolution.    Microphyll, macrophyll and articulated stem are indicating lines.
    (3)    Arrangement of female cones (Fig. 10)
    Cones were not yet in Protolepidodendrales and formed in Lepidodendrales.    The
sporophylls were spaced around the stem without forming cones in Protolepidoden-
drales and in Lepidodendrales, sporophylls were aggregated in terminal cones, which
should be called the primary cones.    Because they were the first cones formed in Micro-
phyllophyta,  and  they  had  become  a  part  of  the  secondary  cones  of  *Cordaianthus*
and Lebachiaceae.
    *Cordaites* is a large arborescent plant and its leaves are very large unlike conifers,
strap-shaped and sometimes over a meter long and 15 cm wide.    The reproductive organ
(inflorescence) consists of two rows of bud-like organ that are described as the secondary
cones (flowers).    The writer interprets that the female cones (inflorescence) of *Cor-
daianthus* are formed by aggregation of many primary cones (flower) of Lepidodend-
rales as shown in Fig. 10.    Therefore a cone (flower) of *Cordaianthus* (inflorescence)
corresponds with the large primary cone of Lepidodendrales which was reduced to the
small type of cone.    The usage of terms, the primary cone and the secondary cone, by
the present writer are not coincide with that of the other writers.    We can trace the
reduced change of the primary cones of Lepidodendrales through the Late Paleozoic,
Mesozoic and Cenozoic by using the same corresponding terms, the primary cone.

Lebachiaceae has the small leaves and the secondary cone which has the many primary cones arranged spirally around the axis. Cordaitales has the large leaves and the secondary cone which has the many primary cones arranged in two opposite rows at side of the cone axis. The latter has the secondary cone formed by aggregation of reduced primary cones and the former has that formed by the enlargement of the primary cone as shown in Fig. 10.

Judging from the reasons mentioned above the writer recognized the two evolutional lines, the *Sigillaria*-Cordaitales line and the *Lepidodendron*-Lebachiaceae line in the evolution of Microphyllophyta. In each line the secondary cone which has the many primary cones around the cone axis reduced to only one primary cone (*Ullmannia*) and again to only one enclosed seed (*Palaeotaxus*, *Podocarpus*, *Taxus*, *Torreya*, etc.) at the end of each evolutional processes.

The writer agrees with the opinion of Harris (1976) who insists the unnecesity of the class Taxopsida and not with that of Florin (1951) about the classification of Taxaceae which contains the Upper Triassic *Palaeotaxus* and the Jurassic *Taxus jurassica*. This will be understood by the explanation and figures mentioned above.

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