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PAPERS OF THE MICHIGAN ACADEMY OF SCIENCE ARTS AND LETTERS

EDITORS

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INTRODUCTION

The silicified plant remains of the Mesozoic and Tertiary of western North America have offered many opportunities for paleobotanical research, which often have been neglected. Although the scarcity of properly trained investigators has been partly responsible for this neglect, a more important element has been the prevailing notion that the material consists only of the secondary wood of gymnosperms and dicotyledons which is so difficult to identify that the effort expended would not be justified by the results obtained. Another deterrent, and one of a practical nature, is that most of these woods are as hard as quartz, and the preparation of thin sections suitable for study requires labor, patience, persistence, and a certain minimum of skill. In addition, properly constructed cutting equipment must be available when any amount of material is to be studied. Cellulose peels, which have been widely used within recent years for coal-ball petrifications, cannot always be successfully made from silicified plants because the etching process often destroys the tissue structure. It is only in woods, usually those with a very dark color, in which the cell walls have retained much of their original organic content, that the intercellular and intracellular...
silica can be dissolved away without the structure suffering severe damage. The brighter and more brilliantly colored woods are usually without much cell structure, and they cannot often be successfully studied even in ground preparations.

Regardless of the technical difficulties that may be encountered in studying silicified plant remains, some spectacular results have been achieved, as is shown by the investigations of Lester F. Ward and George R. Wieland on the cycadeoids of the Black Hills and Freezout Mountain regions of South Dakota and Wyoming. In this group of extinct plants the vegetative and reproductive structures have been analyzed to a degree of completeness approaching that of Recent species. Then there are other instances, on a much smaller scale, of noteworthy achievements in the study of silicified plants from the western states, but no groups other than the cycadeoids have been subjected to thoroughgoing and systematic investigations. Leaf impressions, on the other hand, have been ardently collected in prodigious quantities for nearly a century. Important results have been obtained, and the literature relating to them amounts to volumes. Although they require no elaborate preparations for study, as do petrifactions, their correct interpretation is often a subtle matter which may tax the ingenuity of even the most experienced investigators.

Plant morphologists showed us long ago that relationships are sometimes revealed through internal structure when external form fails. This is especially true in paleobotany, for the whole plant with all parts attached is seldom found. An outstanding example of this principle was the discovery during the latter part of the last century of petrified stems in the Coal Measures which showed a combination of filicinean and cycadean characteristics, but which occurred among foliage ordinarily regarded as belonging to ferns. The conclusion based upon the anatomical evidence was that here exists a member of an extinct group occupying intermediate status, a supposition later substantiated when seeds were found attached to the foliage. Thus, the greater the evidence that can be brought to bear upon any particular problem, the more conclusive the results will be. Anatomical evidence has been used more extensively for Paleozoic plants than for later ones, but it is a useful adjunct even in the classification of Recent species.

The majority of the silicified plants of western North America are woody dicotyledons, followed in decreasing order by conifers, monocotyledons (principally palms), cycadeoids, and ferns. As has been stated, only the cycadeoids have been comprehensively studied. The present account is concerned with two new genera and five new species of ferns which range from the early or middle Cretaceous into the Eocene. The assembling of the material was made possible only through the cooperation of several collectors, most of whom are residents of the regions from which it came. Those who have furnished or lent specimens for study are Mr. V. D. Hill, Mr. J. W. Berry, Mrs. Ethel Smith, Mr. H. Timmel, Mr. and Mrs. F. W. Dennler, Mr. George Futa, Mr. Fred Salfisberg, and the late Mr. Louis Wessel.

I. AN OSMUNDITES FROM CENTRAL OREGON

To date only two structurally preserved stems of Osmundites have been reported from North America. O. skidegatensis was described by Penhallow (16) from the Lower Cretaceous of the Queen Charlotte Islands in 1902, and in 1941 Daugherty (10) described O. walkeri from the Triassic of Arizona. The discovery of a third specimen in the Tertiary of Oregon is of special interest in that it supplies evidence, in addition to that furnished by foliage compressions, of the westward extension during that period of osmundaceous ferns which at present in North America are restricted to the eastern part of the continent.

The specimen, a transverse slice about 3 cm. in thickness of a silicified stem approximately 6 cm. in diameter, was noticed by the author among a collection of agates owned by Mr. V. D. Hill, of Salem, Oregon. Mr. Hill very kindly submitted a portion of the specimen for study. The stem was originally found by other persons, who refused to divulge the exact source, but inquiry has revealed that it came from within ten miles of Post, Oregon. For this reason it seems improbable that the specimen could have come from any formation other than Tertiary. Post is located on the Crooked River slightly to the southwest of the center of the state, and the formations in that region range from early Tertiary to Miocene. The oldest formation in the vicinity of Post is the Clarno, which is believed to be either Eocene or early Oligocene. The Clarno is overlain unconformably by the John Day series. The lower portion of the John Day series contains the Bridge Creek plant-bearing shales, which are believed to be of upper Oligocene age. Above the John Day is the Columbia lava, followed by the Mascall formation, which belongs to the Miocene. No Cretaceous or older beds have been definitely recognized nearer than Paulina, which is about thirty miles from Post.

Plants have been found along the Crooked River in the Clarno and Bridge Creek shales, and the largest flora was secured from the latter at Gray's Ranch, eleven miles east of Post (Chaney, 8). These plant occurrences offer no proof, however, that the Osmundites stem came from the Clarno or the Bridge Creek beds, because silicified plant material is common in the Tertiary sediments throughout the whole area. Nevertheless, the presumptive evidence is that it is not older than Eocene or younger than Miocene.

The specimen is highly agatized, and although its tissues are very poorly preserved, its generic identity is evident even upon casual observation. In the center are two vascular cylinders which diverge slightly from one transverse surface of the specimen to the other. This shows that the cut was made just above a fork in the
stem (Pl. I, Fig. 1). Both axes are enclosed by a thick mantle of adhering leaf bases which in osmundaceous ferns, both living and fossil, makes up the bulk of the trunks. The leaf bases are oval in cross section, with a C-shaped vascular strand in which the concavity is turned toward the center (Pl. I, Fig. 2). At one side of the specimen the outermost leaf bases are oriented in the opposite direction, which shows that the stem had forked a second time at a lower level (Pl. I, Fig. 1, at left). Since branching is infrequent in the living species of _Osmunda_, it is remarkable to find evidence of two rather close dichotomies in a fossil specimen.

Each vascular cylinder is about 6 mm. in diameter. Tissue preservation is very poor, and about all that can be said concerning the structure is that the xylem appears to consist of sixteen or more separate strands around a central pith. The distribution of the phloem and the endodermis, features essential in comparing material with Recent species, is undeterminable. Around the almost clear silica-filled vascular region is the brownish cortical layer through which several leaf traces pass. In the cortex the xylem of the trace is a small reniform mass of tracheids (one of the few places where cells can be seen) with the indentation innermost. As the trace emerges from the cortex the indentation becomes deeper and the petiole base is surrounded by a layer of dark-brown supporting tissue. Those petioles to the outside of the mantle become increasingly larger until they reach a maximum tangential diameter of about 7 mm. Passing outwardly in a more or less horizontal direction among the petiole bases are numerous adventitious roots (Pl. I, Fig. 2).

The geological history of the Osmundaceae is better known than that of most Recent fern families. Structurally preserved stems known as _Zalesskya_ and _Thamnopteris_, which are undoubtedly members of the Osmundaceae, occur in the Permian. There are no undisputed records of osmundaceous ferns in older Paleozoic rocks, although the family may be foreshadowed by fructifications and stems of the Lower and Upper Carboniferous usually assigned to the Botryopteridaceae. Stems definitely referable to Osmundites are known from the Triassic rocks (Kidston and Gwynne-Vaughan, 13; Daugherty, 10), but the genus appears to have reached the height of its development during the Jurassic.

_Osmunda_ (Osmundites) is rare in the Tertiary of North America, probably having disappeared entirely from the western part of the continent during the middle or the latter part of that period. It is rarely found in rocks younger than Eocene, and is not common even there. However, it is possible that from time to time the genus has been overlooked because of the ease with which the barren foliage may be mistaken for that of other genera. The frond fragments described by C. C. Hall (in Chaney, 8, p. 100) as _Pteris silvicola_, from the Gray Ranch along the Crooked River, are quite similar to the normal frond parts of the eastern _Osmunda cinnamomea_, and could, it seems, be assigned to this species as readily as to the bracken fern. The bracken, of course, is a member of the coastal redwood association with which the Bridge Creek flora has much in common, but the Bridge Creek flora also contains an eastern element of eight species to which _Osmunda_ would be a not unexpected addition.

On account of poor preservation of the tissues it is impossible to compare the specimen in detail with living or fossil species other than to note a general similarity with the cinnamon fern _Osmunda cinnamomea_. However, in the absence of material showing the presence of internal phloem in the vicinity of the branches its identity with this species cannot be more than merely suggested. It is given the name _Osmundites oregonensis_ in order that it may be placed on record and that future reference to it may be facilitated. It is hoped that subsequent discoveries will reveal the structure more adequately.

**Osmundites oregonensis**, sp. nov.—Dichotomously branched stems surrounded by a thick mantle of leaf bases and adventitious roots. Xylem cylinder of 16-20 separate strands surrounding a pith. Outermost petioles of mantle oval, about 7 mm. broad, and each containing a C-shaped xylem strand.


II. A FERN PETIOLE FROM THE GREEN RIVER FORMATION

The following description is based upon some silicified petiole fragments which, when first examined, were thought to belong to a monocotyledon, but the lack of vessels, combined with the distribution of the bundles, seems to furnish indisputable evidence that they represent a fern. Cycadaceous affinities are excluded by the absence of centripetal wood in the bundles and by the lack of mucilage canals. The specimens came from the Eocene Green River formation and were collected in the so-called Eden Valley petrified forest, which is located about twenty-six miles east of Farson, Sweetwater County, Wyoming, and about six miles east of the Hay Ranch. This locality has long been famous for its delicately colored agatized limbs, of which large quantities have been removed by gem-stone collectors. It also yields palm trunks and other plant remains. No systematic study, however, of the petrifactions from this place has been made.

The petioles, which range from 12 to 22 mm. in diameter, are rounded or slightly angular, with a broad adaxial furrow (Pl. II, Fig. 1). The outer part consists of a layer of sclerenchyma made up of small, compact, thick-walled fibers, and the interior contains collateral bundles distributed throughout a ground tissue of thin-walled cells and large intercellular spaces (Pl. II, Fig. 2). Each bundle is surrounded by a sheath of fibers several cells in extent, and the fibrous sheaths of the outermost layer of bundles are connected with the external sclerenchyma by a narrow isthmus of fibers. In most bundles the phloem and the accompanying parenchyma have disintegrated and thus have left the xylem...
somewhat displaced from its original position within the large oval or circular bundle cavity, but the orientation of the xylem and the phloem is usually evident from the position of the protoxylem. Longitudinal sections show that the xylem consists of scalariform tracheids. In some of the bundles there is evidence of a thin-walled endodermis inside the sclerenchymatous sheath.

The bundles are distributed according to a definite plan, although partial disintegration of the tissues in parts of all sections that have been examined interfered with the determination of the arrangement. Moreover, the arrangement is not identical in any two specimens, although there is evidence that the differences are merely modifications of one type. In the large leaf stalks, where there are two hundred or more bundles, the arrangement is more complex than that in the smaller ones with fewer bundles.

Extending across the bottom of the petiole section and up both sides is the peripheral bundle layer, in which the phloem is toward the outside and the xylem to the inside (Fig. 1A, d). At its upper extremities the ends of the bundle bands turn inward, and they extend downward as bands internal to the outer layer with the phloem and xylem oriented in the opposite direction (Fig. 1A, e). Extending across the top of the petiole section is another band (Fig. 1A, a) of bundles in which the xylem is toward the outside. At the mid-point of this band (Fig. 1A, b) there is a double bundle from which two bands of bundles extend deep into the interior of the petiole (Fig. 1A, c) on opposite sides of the median line. The arrangement from here on is slightly uncertain, but these median bands appear ultimately, after undergoing a few minor folds, to connect with the infolds of the lateral peripheral bands just described.

Among living ferns Blechnum zamioides shows a bundle pattern in the petiole that is apparently a modification of the same arrangement (Thomae, 24, Pl. VI, Fig. 2a). The Recent and the fossil petioles agree in having a transverse adaxial bundle band in which the xylem is turned toward the outside. Then from the double median bundle (Fig. 1B, b) two bands extend into the interior. Thomae interprets the bundle complex in B. zamioides as having been derived from two strands arranged in an arc, but with the sides infolded in such a manner as to resemble two figure 5's with one turned to face the other (Fig. 2). The halves of the transverse adaxial bundle consist of two side segments connected at the median line of the petiole by a double bundle (Fig. 1B, b). These are continuous with the deeply infolded bands which loop downward and then upward in the interior and finally extend along the periphery, terminating at the abaxial side of the petiole at the median line (Fig. 1B, c, d, e). The pattern in the fossil form, is believed to be similar to this in several respects at least, although it may be somewhat modified. At the bottom of the section and extending crosswise to the median vertical line there are two bands arranged in a flat transverse oval which represent either additional bands or branches from the two lateral ones (Fig. 1 A, f, g). The former of these alternatives seems more probable.

Fig. 1. Diagrams, A and B, showing the bundle distribution in *Eorhachis lomarioides* and *Blechnum zamioides*, respectively. The lower-case letters identify similar structures in each: a, adaxial segments with outwardly directed xylem; b, double bundle; c, internal bundle bands flanking median line of petiole; d, peripheral bundle band; e, inward extension; f, g, internal bundle bands. A, tracing from original; B, after Thomae.

The resemblances noted between the fossil petiole and that of *Blechnum zamioides* would suggest relationship with the Aspleniaceae. It should be mentioned, however, that very little information is available concerning *B. zamioides*. It is not listed by Christensen in his *Index Filicum*, and Thomae states that the structure deviates considerably from that of other and more typical members of the genus. Therefore, since the Recent fern which most closely resembles the fossil is apparently atypical of the genus to which it belongs, and is little known, the exact relationships of the fossil are dubious, and the suggested affinity with the Aspleniaceae rests only upon such interpretations of the bundle distribution as are possible from the material at hand and the resemblances to Thomae’s figure of *B. zamioides*. Resemblances of a still remoter nature may also exist among certain members of the Polypodiaceae, and the structure of the ground tissue also compares with that of *Ceratopteris* of the Parkeriaceae. There is little or nothing to invite comparison with the Cyatheaceae or the Marattiaceae. In the former the numerous bundles of the petiole are arranged in an upper and a lower series, with the phloem of the upper
series to the outside, and in those of the Marattiaceae that may be compared (as in Angiopteris) there is an evident cyclic arrangement.

Blechnum zamioides belongs to the subgenus Lomaria, which is distributed at present throughout the East Indies, Australasia, and Madagascar. No members of the genus Blechnum have so far been reported from the Green River formation, and the only representative in it of the Aspleniaceae is Asplenium eolithicum. In fact, only seven ferns have been identified from the entire Green River formation (Brown, 6). Considering the warm-temperate nature of the Green River flora it is only to be expected that it will ultimately be found to contain additional fern types, especially those which at present do not exist so far north.

The fern represented here evidently was a water plant or one which was rooted in very wet soil. Apparently it bore fairly large fronds, as is indicated by the amount of sclerenchyma present, and in habit it might have resembled some of the Recent species of Blechnum which are small tree ferns. In view of the uncertainties concerning relationships it seems advisable not to refer this plant to any genus of Recent ferns, but to follow the established practice in paleobotany of creating form genera for such remains. The generic epithet Eorhachis is therefore proposed for this ancient fern petiole of uncertain affinity.

Eorhachis lomarioides, gen. et sp. nov. — Fernlike petiole, rounded or angular in cross section, with a broad adaxial groove or concavity; 10-22 or more mm. in diameter; bundles numerous, collateral, surrounded by sclerenchymatous sheath, and arranged in two or more series, which are probably derived from solid strands arranged in an arc; peripheral bundles normally oriented, those of adaxial band reversed; supported externally by a thin layer of sclerenchyma; ground tissue with numerous intercellular spaces suggestive of an aquatic habit.


III. A TREE FERN FROM SOUTHERN TEXAS

In 1934 Miss Elzada Clover and Mrs. Eleanor Cook Beard secured several silicified tree-fern specimens from a locality about ten miles north of Roma, Starr County, Texas. The exact place is not on record, but the probabilities are that the stems came from the Fayette formation of the lower Upper Eocene. There is also a chance that they came from the underlying Yegua formation (also known as the Cockfield), which has yielded plant remains, including silicified palm trunks (Berry, 3; Sellards and others, 18), but in his account of the Cenozoic geology of the lower Rio Grande valley Trowbridge (25) makes numerous references to silicified wood in the basal part of the Fayette. According to the geological map accompanying Trowbridge's paper, a considerable area extending to within a short distance north of Roma is covered by the Fayette formation, with the Yegua outcropping a short distance to the west. The Fayette lies conformably upon the Yegua, and Berry (3) believes that part of what is commonly regarded as Yegua may belong to the overlying formation. So even though the exact stratigraphic position of the rocks from which the fern material came may be in doubt, it is either upper Middle Eocene or lower Upper Eocene, probably the latter.

The specimens are of small trunks ranging from 5 to 10 or more cm. in diameter. The surface is uneven because of the projecting leaf bases, which form a mantle over the stem (Pl. III, Fig. 1). The leaves did not become detached by any normal shedding process, and they remained in place until removed by decay or abrasion. The leaf bases are arranged in a close spiral and project from the stem at an angle of about 45 degrees. In a cross section about twelve leaf bases may be seen in various stages of departure (Pl. IV, Fig. 1; Text Fig. 3). The higher ones show only as outward bulges of the solenostele, whereas the lower ones may be almost detached. The free portions of the petioles are 2 cm. or less in diameter.

Covering the surface of the stem between the leaf bases is a ramentum of flattened, overlapping multicellular hairs which vary from 1 to 2 mm. in width and up to 1 cm. in length. In cross section they are spindle-shaped and eight to twelve cells thick along the middle portion (Pl. VI, Fig. 3). The light-colored interior of the hair is surrounded by a darker layer three or more cells in depth. The cell walls throughout the hair are thick, which probably made them stiff and bristle-like. The significance of these hairs with respect to the relationships of the plant is discussed later.

ANATOMY

The stems are thoroughly silicified, and in most specimens only the gross anatomical features are visible. In only a few is preservation such that minute details can be satisfactorily studied. Unweathered broken or cut surfaces have a brownish color, which is often quite patchy and uneven, with the result that it is difficult to obtain good photographs of some of the structures. It was impossible to prepare satisfactory cellulose peels, but petrotome sections of some of the specimens show details well if ground sufficiently thin. Smoothly ground surfaces covered with a thin solution of isobutyl methacrylate in xylol and allowed to dry were sufficient in nearly all instances to show everything except the most minute structural details. Such preparations were especially useful in examining large surfaces, and with reflected light it was even possible to see considerable detail under the low power of the compound microscope. They could be very satisfactorily studied with the Greenough-type binocular microscope.

In cross section the outline of the trunks is irregular because of the unevenly projecting but closely spaced leaf bases (Pl. IV, Fig. 2). Very little is known of the...
epidermis or the thin cortical layer other than the mere fact that they are present beneath the ramentum. The surface covered by the ramentum is very small because of the size and close proximity of the leaf bases, and as a result of the leaf-base mantle and the ramentum no part of the stem surface was exposed.

Only a few millimeters inside the surface to which the mantle and ramentum are attached is a deeply fluted irregular solenostele, the continuity of which is rarely if at all interrupted by leaf gaps (Pl. IV, Fig. 1; Text Fig. 3). The xylem of the solenostele shows on the smooth polished surfaces as a light band 1 mm. or less in thickness, but flanking it on both sides is a sclerenchymatous layer of about equal thickness (Pl. VI, Fig. 2). The thin phloem which originally accompanied the xylem on both sides is not preserved, and the space is filled with disorganized material. The xylem consists of angular scalariform tracheids which, however, are seldom cut crosswise in a transverse section. Instead of extending vertically, they often lie transversely or at an angle, or, as may be seen at numerous places, they appear much contorted and follow an irregular course. This irregularity, however, is due in part to the course of the xylem itself. Lengthwise sections show that the vertical course of the xylem is irregular, with frequent bends that often reverse the direction of the layer for short distances. Consequently, sections cut transversely to the axis never pass through all parts of the xylem at right angles to its up-and-down direction.

Owing to the general state of preservation structural details of the xylem are difficult to observe, but there is no reason to believe that it differs markedly from ordinary fern xylem. It consists mostly of scalariform tracheids with but little intermixed parenchyma. The protoxylem has not been identified (Pl. VI, Fig. 4).

The pith, or that part enclosed by the solenostele, contains numerous medullary bundles, often so closely packed that little or no space remains for typical pith tissue. No attempt was made to form even an approximate idea of the number of these medullary bundles, but they can probably be counted by hundreds. Only a very few instances have been observed of a direct connection between the medullary bundles and the solenostele, so that the relation between these two parts of the stelar system is unknown. Those toward the center of the pith tend, however, to be more irregular in size and shape than those near the periphery and to branch more frequently. Also, they do not all follow a vertical course, but many of them extend crosswise or bend in various ways. The outermost ones are more rounded in cross section and follow a more vertical direction. This slight difference in bundle structure in the inner and outer parts of the pith is suggestive of a modified polycyclic condition, although there is no strong evidence to support this interpretation. It does not seem likely, however, that such an elaborate system of medullary bundles as is seen here is related entirely to the solenostele. Numerous medullary bundles pass outward through the foliar portholes from the pith region into the petioles, each receiving nearly a hundred strands (Pl. V, Fig. 1). At the petiole base these strands are embraced within the hollow of the gutter-like trace, and farther out they are still partly surrounded by the separate strands into which the trace becomes divided. They remain readily distinguishable from the trace strands by their smaller size.

The medullary bundles are approximately 0.5 mm. in diameter (Pl. VI, Fig. 1). In most of them the xylem is not preserved, and only the thick sclerenchymatous sheath surrounding each one is left.

The continuity of the solenostele and the seeming absence of leaf gaps in the transverse section of the stem is one of its distinctive and most interesting features. It has been possible by means of a series of slices cut transversely to the petioles but oblique to the transverse plane of the stem to follow the course of the vascular supply of the petiole from the points of its inception to the nearly complete leaf stalk (Fig. 4). The petiole bases these strands are embraced within the hollow of the gutter-like trace, and farther out they are still partly surrounded by the separate strands into which the trace becomes divided. They remain readily distinguishable from the trace strands by their smaller size.

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separate strands it becomes rather long (Fig. 3 at a; Pl. V, Fig. 1). It is evident that the passageway from the medullary region into this tongue-like loop is the morphological equivalent of the leaf gap, but since the opening through the solenostele closes at a level no higher than the acropetal margins of the trough, and since the trough at this level has not yet broken into separate strands, no break is visible in the continuity of the solenostele within a transverse section. A solenostelic instead of a meristelic condition results, therefore, from the abrupt closure of the leaf gap above the point of trace departure. The gap, however, is present in a morphological sense, but it passes obliquely to the point of trace departure. The gap is therefore, from the abrupt closure of the leaf gap above the acropetal margins, a solenostele instead of a meristele condition results, the solenostele within a transverse section. A medullary region into this tongue-like loop is the "roof." The vertical interval between B and C is 1 mm. At D and shows the form of the trough-shaped leaf trace with its inturned margins and the two curved strands of the roof r. All changes in the configuration of the solenostele from the bottom to the top of the gap a short "compensation tongue" was found to join the lateral margins of the solenostele at the point where the gap would be expected to continue above the acropetal margins of the trace strand (Pl. V, Fig. 2; Text Fig. 4a). This short downwardly projecting flap of the solenostele appears to be mainly responsible for the closing of the upper part of the gap (Fig. 4b), where it would otherwise occur and cause a break in the continuity of the stele in cross section.

Downward, the tongue narrows abruptly, and within a distance of 2 or 3 mm., or at about the median level of the departing trace, it loses itself among the medullary strands (Pl. V, Fig. 1). Before the tongue becomes detached from the solenostele it is easily distinguishable as the inward bend previously mentioned (Pl. V, Figs. 3-4). This compensation tongue seems to be similar to that described by Tansley (23) in Matonia pectinata and by Bower (4) in Thyspezepis elegans. In both these ferns the compensation tongue closes the leaf gap and forms a continuous unbroken solenostele. A continuous solenostele has also been observed in a few other ferns, including Pteris alata var. Karsteniana and Dicksonia adiantoides (Gwynne-Vaughan, 11), but in them the closure is due to a very low leaf gap.

When cross sections of the petiole bases are examined other structures are visible in addition to the trough-shaped strand and the accompanying medullary strands. Lying above the trough and covering the central part like a roof are one or two additional transversely broadened strands which somewhat resemble the lower strand except that it is slightly shorter and less curved. They are inverted with respect to the lower strand (Fig. 4e), with their concave sides downward (uppermost in the figure). At first the origin of these "roof" strands was a mystery because at no place could they be seen attached to or in any way connected with the solenostele, and they are not present over the main trace strand at the level where the compensation tongue closes the gap. However, upon examination of carefully cut oblique sections, it was found that this "roof" originates by the broadening and lateral joining of two or more medullary strands which enter the leaf gap immediately dorsal to the compensation tongue (Fig. 4c-e). The entire leaf-trace supply consists, therefore, of tissue derived from both the solenostele and the medullary bundle system.

Small adventitious roots spring from the abaxial side of the petiole base (Fig. 4d-e).

**AFFINITIES**

The affinities of this plant are believed to be with the Cyatheaceae, the family which includes the majority of the living tree ferns. The most obvious cyatheoid features are the arborescent habit and the general plan of the vascular system. It differs from the more typical members of the family in having an unbroken...
solenostele. In most species the continuity of the stele is broken at the places where the leaf traces depart by rather wide gaps, and thus separate the vascular ring into meristeles. The difference between these two so-called stelar types is, however, merely a matter of the vertical extent of the leaf gaps and is therefore not a fundamental one, even though the aspect produced by the two in cross section is quite different.

In comparing the fossil fern with living members of the Cyatheaceae the problem is rendered difficult because of our ignorance of the vascular anatomy of many tree ferns growing at present in the Western Hemisphere. The locality from which the material came is only a few hundred miles north of the present range of tree ferns in Mexico, and it is possible that the living equivalents of the Eocene fern may still thrive among the numerous species of the Cyatheaceae now growing in Mexico or Central America. Until these living ferns are made the subject of a comprehensive anatomical study, it is futile to speculate at length upon this possibility. The most extensive anatomical study of tree ferns made within recent years is by Ogura (14), who gives a detailed account of the eight species found in Japan and Formosa. All the species treated by him have distinct leaf gaps and therefore lack the feature most prominently displayed in our form.

The Cyatheaceae are divided by most authors into three tribes, the Dicksonieae, the Thyrsopterideae, and the Cyatheae. The fossil apparently does not belong exclusively to any of these tribes, but shows instead characteristics common to all three. Considering first the Dicksonieae, we find in Cibotium Barometz a leaf trace which begins as a single gutter-shaped strand with deep lateral folds, but soon breaks into separate bundles. C. Barometz, however, has a creeping rhizome, although other members of the genus (as well as the Dicksonieae in general) are upright. Most members of the Dicksonieae lack medullary bundles, although occasionally, as in Dicksonia rubiginosa, internal thickenings of the solenostele may become detached and form internal strands in the internodes (Gwynne-Vaughan, 11).

The Thyrsopterideae contain one species, Thyrsopteris elegans, which is restricted in its present natural haunts to the island of Juan Fernandez. Probably the foremost point in common between this fern and the fossil is the compensation tongue, already mentioned, which closes the leaf gap above the departing trace, although this structure is present also in Matonia pectinata of the Matoniaceae. In Thyrsopteris the leaf trace departs from the solenostele as a continuous wavy band, but the sclerenchymatous sheath usually present in the cyatheoids is lacking.

The third tribe, the Cyatheae, contains three genera, Alsophila, Hemitelia, and Cyathea, all of which are typically meristelic with medullary strands and leaf traces divided into numerous bundles from the place of their origin. In Alsophila pruinata, however, the trace is a horseshoe-shaped band more like that of Cibotium Barometz, Thyrsopteris elegans, and the Eocene form. Although A. pruinata is described as siphonostelic (solenostelic), the condition is the result of long internodes and not of small gaps. The solenostelic condition in A. pruinata and the fossil species is, therefore, fundamentally different, and does not furnish a satisfactory basis for comparison.

Concerning the phylogenetic significance of the composite character of this fern, the offhand proposal might be proffered that it is a generalized ancestral type from which the Recent tribes have become segregated. This, however, does not seem as probable as an alternate one that it represents a separate line. In accepting the first hypothesis it becomes necessary to assume that the Recent tribes owe some of their differences to the loss of certain distinctive anatomical features. For example, the Dicksonieae would have lost most of the medullary strand complex and the compensation tongue, the Thyrsopterideae would have retained the latter structure but lost the sclerenchyma, and the Cyatheae would have lost the compensation tongue and the solid trace strand. It is hardly possible that the medullary strand system, including the compensation tongue, is a primitive feature, so that, with the exception of the troughlike trace strand (which is primitive), the Texas fern probably represents a condition of development about as advanced as any of the living members of the Cyatheaceae. There is no evidence that any of the tribes of the Cyatheaceae originated from ancestors more structurally complex. The original type was probably a simple form not embodying so many seemingly advanced features as are found here.

Although the fossil reveals a combination of tribal characters, it is believed that the sum total of its features indicates a place between the Thyrsopterideae and the Cyatheae. This view, nevertheless, is subject to future modification since it is based mostly upon the well-developed system of medullary bundles, the sclerenchymatous sheath, the trough-shaped leaf-trace strand, and the compensation tongue. Were it not for the compensation tongue this same set of characters would point toward the Dicksonieae instead of the Thyrsopterideae, because in the latter tribe the sclerenchyma is lacking. So it is a matter of choosing between the compensation tongue and the sclerenchyma as a criterion of affinity, and the view is taken that structures in the vascular system should be selected as having more fundamental phylogenetic meaning than extravascular tissues.

Little may be said by way of comparison with any particular genus of the Cyatheaceae. The three genera Alsophila, Hemitelia, and Cyathea are separated solely on the basis of whether the indusium is absent, partial, or complete, and from the purely anatomical standpoint they are indistinguishable as at present defined.
COMPARISONS WITH OTHER FOSSIL FERNS

Because of the widespread practice of comparing with Recent genera compressions of the sterile foliage of fossil ferns in which fructifications or other evidences of affinity are lacking, the early history of the Cyatheaceae is veiled in the same uncertainty that surrounds most of the other fern families. Plants from rocks as ancient as the Culm (equivalent to Lower Carboniferous or Mississippian) have been assigned to the Cyatheaceae, although on evidence that is not satisfactory. Our knowledge of the family properly begins with the late Triassic or Jurassic, in which several frond types bearing cyatheoid fructifications are known. Remains of stems showing either surface features or internal structure resembling the Cyatheaceae appear rather abundantly in the Wealden (basal Lower Cretaceous) of Europe. This shows that the family was more widely distributed in the past than it is now. Up to the present no petrified cyatheoid stems have been reported from North America, and the fossil record of the family consists of a few foliar remains ranging from the Triassic to the Eocene. At no time do the Cyatheaceae ever appear to have been abundant in North America, and it is noteworthy that in the large Wilcox flora of Eocene age they have not been recognized. The Eocene probably marks their last stand north of Mexico, and as the tropical Eocene climates gave way to more temperate conditions the tree ferns retreated southward along with the palms and other tropical plants.

Because soral and sporangial differences are employed much more generally than anatomical characteristics in distinguishing the genera of living ferns, it is frequently impossible to assign fossil stems in these genera, even though the relationships may be obvious. It is therefore often necessary to give special generic names to fossil forms. In the Cyatheaceae the three genera Alsophila, Hemitelia, and Cythea do not show anatomical differences that correspond to differences in the indusium; hence fossil stems resembling any of these must be placed in separate groups. The literature contains a number of generic names that have been applied to fossils believed to represent the Cyatheaceae, some of which are Alsophilina, Oncopteris, Cythocaulis, Cebotioicaulis, Caulopteris, Protopteris, and Dendropteridium. Alsophilina and Oncopteris were originally applied to surface impressions and, therefore, are not suitable for structurally preserved material. Caulopteris, also an impression, is used mostly for Carboniferous stems known to possess the internal structure of Psaronius. The remaining names, Cythocaulis, Cebotioicaulis, Protopteris, and Dendropteridium, embrace the majority if not all of the known petrified cyatheaceous stems of all ages. Protopteris, the first to be proposed (Presl, in Sternberg, 22), refers to stems of tree ferns in which the petiole scar bears a horseshoe-shaped leaf-trace imprint indented at the sides. The leaf bases are spirally arranged about a central axis which contains bandlike vascular bundles, usually in the form of meristeles. Seward (19) provisionally places Protopteris in the Cyatheaceae because of its resemblance to Dicksonia antarctica. Its several species are confined mainly to the Lower Cretaceous.

Cyplotheca and Cebotioicaulis were described by Ogura (15) from the Upper Jurassic and Cretaceous of Japan. Both these genera have large leaf gaps, curved ribbon-like meristeles, and medullary bundles. The names are given apparently in allusion to the similarities of the leaf traces to those of Cythea and Cebotioicaulis, respectively, but as pointed out by Bancroft (2), they differ from these genera in having medullary roots and inturned meristele margins. Cebotioicaulis differs further from Cebotioicaulis in its medullary bundles. On the other hand, there is little question that they both belong to the Cyatheaceae, and probably to the tribe Cyatheae. Ogura’s genera contain but one species each, Cythocaulis naktangensis and Cebotioicaulis Tateiwa. Dendropteridium, also having but one species, D. cyplothecoides, was described by Bancroft (2) from the Tertiary of East Africa. The specimen described is typically cyatheaceous with medullary bundles, curved meristeles, large leaf gaps, and separate trace strands. Dendropteridium is proposed as a form genus “for fossil fern stems of dendroid dimensions, of which, in the absence of associated vegetative and reproductive material, the exact affinities are unknown” (2, p. 251).

Of the four genera of fossil ferns described above (Protopteris, Cythocaulis, Cebotioicaulis, and Dendropteridium) none are acceptable for the fern described here. It may resemble Protopteris in several respects, but this genus is generally used for stems which show the horseshoe-shaped trace strand on the surface, and this feature has been stressed by most authors (for example, by Corda, 9, and Seward, 19, 20). There are differences of opinion, however, regarding the taxonomic value of the shape of the trace scar, but since it always enters into specific descriptions and since some species are based almost entirely upon it, the writer does not deem it advisable to use the name Protopteris for specimens in which the trace scar does not show at all on the surface. Moreover, little is known about the anatomy of Protopteris. Corda (9), Seward (19, 20), and others have shown that the distribution of the vascular strands is similar to that of the Dicksonieae, but, lacking details, the published figures are insufficient for accurate comparisons. Of course, some degree of relationship between our fern and Protopteris is possible in view of the trough-shaped trace strand, which both have in common with the Dicksonieae and the Thyspopteridaceae. But, as has been shown, the trace supply of the Texas fern is complicated and consists of strands derived from the medullary system as well as from the solenosteole.

There is little in the structure of Cythocaulis that draws comparison other than its general cyatheoid features. It has a system of medullary bundles, but it differs in being meristic and in having large leaf gaps and separate trace strands. Cebotioicaulis is similarly removed from our fern, although the leaf trace does arise as a...
continuous band, which soon breaks up into separate bundles, and the petiole bases adhere to the stem surface.

As previously explained, the genus *Dendropteridium* was proposed for fossil tree-fern stems the affinities of which are in doubt because of the absence of associated diagnostic vegetative or reproductive parts. Of the four fossil genera under consideration this one is probably the most suitable for the reception of the Texas fern, although it is not an entirely appropriate one. *Dendropteridium* was proposed as a form genus, and apparently was intended for any structurally preserved tree fern that could not be assigned elsewhere. But in our fern the cyatheaceous affinities are hardly to be questioned; hence it should not be placed within a genus which in the future may receive forms not related to the Cyatheaceae. The problem of generic or tribal relationships of our fern arises not only from a lack of associated fronds and fructifications, but also from its peculiar anatomical structure, and to assign it to a form genus such as *Dendropteridium* would be to ignore the value of the anatomical features in its classification. Furthermore, placing it in *Dendropteridium* would be making it congeneric with another species which we know is different; hence the assignment would be entirely arbitrary. The only logical or satisfactory procedure, it seems, is to place the Texas fern within a genus of its own. An alternative would be to amend the genus *Protopteris* (which it resembles more closely than *Protopteridium*) so as to include it, but this should not be done solely on the basis of the published descriptions. It would be necessary to examine some of the original material and to elucidate the anatomical structure more completely.

Since no previously described genus, either living or fossil, seems appropriate for the reception of the Texas tree fern, the name *Cyathodendron* is proposed for it. The diagnosis is as follows.

*Cyathodendron texanum*, gen. et sp. nov. — Stems upright, covered with a mantle of spirally arranged leaf bases and flattened multicellular hairs; vascular system a solenostele accompanied by numerous medullary bundles; all vascular parts surrounded by sclerenchyma; solenostele continuous; leaf gaps small and closed above departing trace by a compensation tongue; leaftrace supply of numerous strands and derived from solenostele and medullary system; solenostelic trace strand a continuous trough-shaped band with incurved margins, and above this, in inverted position, one or two similar bands formed by fusion of medullary strands passing into the petiole; numerous single medullary strands also present in petiole; adventitious roots arising from abaxial surface of petiole base.


### IV. THE GENUS TEMPSKYA CORDA

Recent investigations have shown that the Mesozoic fern genus *Tempskya* is widely distributed in the western part of the United States, especially in the middle and northern Rocky Mountain regions, and further investigations will probably reveal a still wider range. It seems rather strange that this distinctive plant should have remained so long in a state of relative obscurity, because well-preserved specimens have reposed in both privately owned collections and in public museums for many years. The probable reason that *Tempskya* has only recently received a share of the attention it deserves is that its silicified false stems bear a superficial resemblance to masses of fossil palm roots, and many have been so identified. Preservation is often such that the real nature of the remains is not evident without thin sections, unless one happens to be on the lookout for it. In some localities, notably at Greenhorn, Oregon, the material is attractively colored and is eagerly sought by amateur collectors as an inexpensive gem stone.

The first description of a *Tempskya* from western North America is Seward’s account of *T. Knowltoni* (Seward, 21), from Wheatland County, Montana. Nothing more was added to our knowledge of the genus until 1936, when Brown (7) published a short paper in which he set forth its gross distinguishing characters. The macroscopic differences between *Tempskya*, *Palmoxylon*, *Psaronius*, and the woody tissues of the conifers and dicotyledons are briefly explained. In 1937 Read and Brown (17) gave a detailed account of the anatomy of three species of *Tempskya*, two of which were new. Ten western localities are listed, a synopsis is given of the American species, and the taxonomic relationships and stratigraphic range are discussed. They conclude that the genus ranges throughout the Cretaceous, but that in western North America it appears to be restricted to the Colorado group, which is approximately mid-Cretaceous. The most recent contribution is a short paper by Andrews (1), in which references are made to occurrences of *Tempskya* in western Wyoming and adjacent Utah.

Several specimens of *Tempskya* have lately been added to the fossil plant collection of the Museum of Paleontology of the University of Michigan. Most of the material is from new localities in Montana and Wyoming, although some portions of false stems have been secured from “Locality 11” of Read and Brown (17, p. 125) at Greenhorn, Oregon. They merely mention this material because it was received by them too late to be described in their report.

The essential gross and microscopic characters of *Tempskya* have been described by previous authors, so that they need not be repeated here. The aim of the present account is to place on record two new localities for the occurrence of the genus and to describe two additional species. The author is convinced that the species of *Tempskya* cannot be identified from macroscopic characters alone, and that microscopic
examination is necessary. Accurate identification is therefore contingent upon satisfactory preservation, and for the more poorly preserved material it may become necessary to establish "form species" based upon the grosser aspects.

**Tempskya Wesseli**, sp. nov. — This species is named in recognition of the late Mr. Louis Wessel, of Great Falls, Montana, who furnished the specimen that is here designated the holotype. According to information furnished by him, it came from the Kootenai formation of the "bad lands" northwest of Great Falls. In this region, however, the Kootenai is overlain by the Colorado group, and since elsewhere in western North America *Tempskya* is known only from the Colorado group, it is possible that this material had weathered out of the higher beds. Mr. Wessel stated explicitly, however, that the material is from the Kootenai, and that it was all found within a vertical interval of about three hundred feet.

To this species is assigned the jasperized material of *Tempskya* from the placer outwash at Greenhorn, Oregon (Pl. VII, Figs. 1-2). Although more abundant than the material from Great Falls, it is less well preserved, so that it is considered advisable to designate as the holotype the specimen showing the best tissue preservation. The following diagnosis is based upon the holotype.

False stems radially symmetrical; individual stems 4-5 mm. in diameter, internodes long, usually showing only one leaf trace in a transverse section; cortex distinctly three-layered; outer layer of thin-walled slightly flattened cells with dark contents, constituting about one fourth of the cortical zone; middle layer slightly thicker, fibrous; inner layer about equal in extent to the middle layer, cells thin-walled, oval, with dark contents and often showing an imperfect radial alignment, the layer containing on the outside a continuous band and on the inside a "discontinuous band of stone cells; outer endodermis present; pericycle and phloem thin (seldom preserved); xylem with considerable interspersed parenchyma; inner endodermis present; pith sclerenchymatous in center, outer parenchyma layer thin.


Owing to the radial construction of the false stem and the complex structure of the cortex, *Tempskya Wesseli* obviously belongs to the *grandis-Rossica* group of *Tempskya* as outlined by Read and Brown (17, p. 119). It differs from the species they placed in this group, however, in having smaller stems and longer internodes, and from *T. grandis* in particular in having two bands of stone cells in the inner cortex. This last character is believed sufficient to justify placing the material in a new species. With respect to size of stems and length of internodes some resemblance to *T. Knowltoni* and *T. minor* may be noted, but these species lack the stone cells in the inner cortex, and the arrangement of the stems is such as to indicate that the false stems grew in a dorsiventral position (Read and Brown, 17). It is apparent from the combination of characteristics present in *T. Wesseli* that stem size and length of internodes are not always linked with the habit of the false stem. As yet we know of no species with large stems and short internodes that have the dorsiventral habit. The dorsiventral forms, on the other hand, may all have small stems, although small stems are not confined to this group.

In view of the fact that the main distinguishing feature of *Tempskya Wesseli* is the double layer of stone cells in the inner cortex, this tissue will be described in some detail (Pl. IX, Figs. 1-2). The whole inner cortex is about one third of a millimeter in extent, although it varies somewhat in different stems and in different parts of the same stem. The outermost sclerenchyma layer is a thin, somewhat irregular band generally not exceeding three or four cells in breadth, which appears to lie along the transition zone between the middle and the inner cortical layers. Whether it belongs to the middle or the inner cortex is not absolutely clear, but the assumption is that it belongs to the inner zone (Pl. IX, Fig. 2). The cells are fairly large and angular and have thick walls and small lumina. Read and Brown refer to them as "gummy sclerenchyma," apparently because of their homogeneous appearance where they are not well preserved and the brownish color of the walls. However, when specimens are examined carefully in thin section, numerous canal-like pits may be seen penetrating the thick walls, indicating that these cells are true stone cells, although in the less well-preserved ones partial disintegration of the wall gives the appearance of a gummy substance. The cells of the inner sclerenchyma layer resemble the outer ones except that they form a band of cell clusters which are isolated from one another by a distance about equal to or slightly less than their own diameter. A peculiarity in the chemical make-up of these stone cells is that in sections prepared by the "peel" method they are not recognizable, which indicates that they are soluble in the hydrofluoric acid used in the etching process. Consequently, if only peel sections were studied, this species would not show its main distinguishing feature.

Between the two stony layers of the inner cortex is a homogeneous tissue of rounded or oval thin-walled cells with dark foamy contents (Pl. IX, Fig. 2). They vary somewhat in size and tend to be flattened against one another in radial rows. Between cells of adjacent rows there are numerous rather large intercellular spaces. The inner cortex is succeeded on the inside by the outer endodermis, which in places is well preserved as a single layer of small thin-walled cells with dark contents. Between the endodermis and the xylem is a zone of thin-walled cells which represents the pericycle and phloem, but these tissues cannot be distinguished from each other. In the stems of the holotype specimen most of the xylem has disappeared, the space having become filled with clear silica (Pl. VIII, Fig. 1; Pl. IX, Fig. 1).
disintegration of the xylem is difficult to explain when the excellent preservation of the other tissues is considered. Nevertheless, small portions are present in which the structure is well revealed. One or more parenchyma cells are usually present in contact with each tracheid. These cells are sometimes isolated and in contact with the shorter tracheid walls, although frequently they occur as chains of three or more cells. Read and Brown place some stress on the prevalence of xylem parenchyma in specific diagnoses. *T. grandis* and *T. Rossica*, according to them, contain much xylem parenchyma, whereas in *T. Knowltoni* and *T. minor* there is said to be little or none. It is evident from the material of Tempskya available for study that there is some variation in the amount of parenchyma in the different species, but whether this character is one of value in distinguishing between species may, it seems, be questioned unless material of the species concerned is available for direct comparison. Because the parenchyma cells are rather regularly distributed among the tracheids — sometimes singly, sometimes in chains of two, three, or more — it is seldom possible to express the condition in concise terms. This difficulty is illustrated by the statement by Read and Brown that in *T. Knowltoni* the xylem parenchyma is composed “almost entirely of scalariform tracheids with almost no xylem parenchyma.” This statement might mean either that parenchyma cells are difficult to find in *T. Knowltoni* or that the total amount of parenchyma is small because of the smaller size of the cells as compared to the proportion of tracheids making up the tissue. It is obvious, however, that in *T. Knowltoni* parenchyma cells are of frequent occurrence in the xylem, but they are usually isolated cells, or sometimes two cells may occur together. In such species as *T. grandis* and *T. Wesseli* the parenchyma cells may form chains of three or, occasionally, more cells which separate the tracheids, but the continuity of the tracheid tissue is not interrupted to any extent.

Lining the inside of the xylem ring is a narrow zone of thin-walled cells apparently consisting of phloem and pericycle, and this is succeeded by the internal endodermis. The endodermis surrounds the pith, which consists of a narrow outer zone of thin-walled cells enclosing the inner sclerenchymatous part. The thick walls of the sclerenchyma are perforated by numerous burrow-like pits.

The form and departure of the frond traces are identical in all essential respects with those of other species of Tempskya (Pl. VIII, Fig. 1). Completely detached petioles are but rarely found in the sections. The xylem arc of the petiole base is a thin broadly horseshoe shaped band slightly flattened abaxially, with the ends slightly enlarged. At this stage they are not curved inwardly, and it seems doubtful that even in the free petiole the extremities become as strongly incurved as those in *T. grandis* and *T. Rossica*, although the exact condition is unknown above the petiole base.

The cortex of the petiole base shows the same structural differentiation as that of the stem, including even the two layers of stone cells in the inner cortex. The outer stony layer is continuous all the way around, but the inner one extends only as far as the xylem arc. No stone cells can be seen along its concave adaxial surface or in the gap between the extremities of the xylem.

The roots of Tempskya Wesselli are well preserved and resemble those of *T. grandis*, which are well illustrated by Read and Brown (5, Pl. 41, Fig. 4). The diarch stele is enclosed by a thick sclerenchymatous cortex, which is bounded on the outside by a layer of large-celled parenchyma (Pl. VIII, Fig. 2). This parenchymatous layer seems to vary considerably in extent. In many roots it has been wholly or partly torn away, and the remaining portions are usually crushed. In a few roots, however, the tissue is complete and forms an outer cortical zone about equal in extent to the sclerenchyma. No filiform root hairs, such as Read and Brown figure in connection with *T. minor*, have been seen in *T. Wesseli*. This outer cortical parenchyma also extends as strips of crumpled tissue into the spaces between the roots and constitutes the binding tissue of the root mass.

Apparently, as new roots grew downward among the older roots, they often penetrated this outer layer, and thus pulled it away from the roots to which it had originally been attached and in many instances tore it loose completely. The outer cortex of these younger roots was in turn penetrated by other roots, with the result that very little of it remains in place.

The foregoing interpretation of the binding tissue of the root mass of the false stem seems to be supported in material identified as Tempskya grandis from Wheatland County, Montana (Pl. XI, Fig. 2). In this material preservation is superior to that of any other specimen so far observed, and sometimes two or more roots are surrounded by a common layer of parenchyma which has become distended beyond its original limits. These roots also bear root hairs.

**Tempskya wyomingensis**, sp. nov. (Pl. X: Pl. XI, Fig. 1).—The material assigned to this species consists of several false stem fragments which were found about twenty miles northeast of Greybull, Bighorn County, Wyoming. The area which yielded the remains lies principally within the valley of Beaver Creek, a southerly flowing tributary of Shell Creek. The eastern portion of the Bighorn Basin lying between Sheep Mountain, just north of Greybull, and the Bighorn Range consists of a shallow syncline in which the sediments range from Paleozoic to Cretaceous. The rocks covering most of the syncline belong to the Colorado group, and beneath it are the Cloverly and the Morrison formations. These latter formations outcrop as a narrow band along the eastern margin of the basin, where they were tilted up by the elevation of the Bighorn Range, but in the vicinity of Beaver Creek they are uncovered over a larger area.

Fragments of Tempskya are widely scattered within the valley of Beaver Creek and its tributaries, but they are nowhere abundant. They have been found only where the Morrison formation is exposed and are associated with enormous numbers of dinosaur bone fragments and
gastroliths; in fact, a few small pieces were found only a mile or two from the quarry of the Sinclair Dinosaur Expedition of 1934 (Brown, 5). Also associated with the fern material are occasional fragments of the trunks of Cycadeoidea, which resemble those from the Freezeout Mountain locality north of Medicine Bow.

The author is indebted to Mr. and Mrs. F. W. Dennler, of Greybull, for most of the material of Tempskya wyomingensis. Another specimen was submitted by Mr. H. Timmel who, with Mr. Leslie Couch, acted as a guide in the Beaver Creek locality in 1941.

The material is not so well preserved as that of Tempskya Wesselii, and some of the histological details admirably displayed by that species are obscure in this one. The xylem cylinder, however, is well preserved, and the false stems had suffered little or no crushing.

Tempskya wyomingensis is very close to T. grandis, and specific separation is made only after considerable deliberation. Its diagnosis is as follows:

False stems radially symmetrical; individual stems 6-8 mm. in diameter, internodes short, with 1-4 leaf traces appearing in each transverse section; free phyllopodia frequent; cortex three-layered; inner layer, which constitutes less than one half of the cortical zone, bounded on outside by a narrow but continuous band of stone cells, and on inside by a discontinuous band occupying one half of the width of the layer; endodermis not visible; xylem with considerable interspersed parenchyma, 5-8 cells in extent, and with an almost continuous zone of small tracheids around periphery; inner and outer phloem and pericycle present; pith mostly fibrous; xylem strand of free petioles (phyllopodia) with strongly incurved margins; roots provided with filiform root hairs.


As already stated, this species is close to Tempskya grandis, and were it not for the double layer of stone cells in the inner cortex (a feature it shares with T. Wesselii) it would be placed within that species without hesitation. Its internodes were evidently shorter than those of T. Wesselii, but longer than those in T. grandis, though it is possible that there was some variability with respect to this feature, as is indicated by the fact that the number of leaf traces per stem section varies from one to three (Pl. XI, Fig. 1). It is difficult to utilize such features as length of the internodes and amount of parenchyma present in the xylem for separating species because of the lack of absolute standards for comparison.

Tempskya wyomingensis agrees with T. grandis in the radial construction of the false stems, in having large stems (6-8 mm. in diameter), in having large petiole bases (four fifths of the diameter of the stem), and in the relatively short internodes. A feature it possesses in common with T. minor, one of the dorsiventral species, is the presence within the root mass of free petioles (Pl. X, Fig. 1; Pl. XI, Fig. 1). These generally lie near the stems. Its point of agreement with T. Wesselii is the double layer of stone cells in the inner cortex, but it disagrees markedly in size of stems.

In the preceding descriptions of the two new species of Tempskya stress is placed upon characteristics which are believed to distinguish them from previously described species, and no effort is expended in elaborating upon the general morphology of the false stem or the more obvious anatomical structure of the vascular system. These phases have been adequately dealt with by previous authors. The main result of this study has been to give a better idea than we have had before of the variety of structures exhibited within the genus which are believed important in separating species, and also to show that in most instances the species can be identified only upon microscopic examination. The segregation of the species by Read and Brown into two groups — those with radially symmetrical false stems and those with the dorsiventral habit — is believed to be basically sound, but with the addition of two new species to the radially symmetrical group this one is now the larger. It appears, however, that the associated characteristics attributed to this group by Read and Brown do not hold because, as shown by T. Wesselii, some of its members have small stems with long internodes. Shorter internodes seem to accompany the larger stems.

Aside from stem size and internode length, which are relative characters and cannot be well expressed in absolute terms, the most dependable basis for specific separation seems to rest in the structure of the cortex. Tempskya grandis, T. Wesselii, and T. wyomingensis all agree in having a three-layered cortex, but the last two are distinguished from the first one by the presence of the double layer of stone cells in the inner zone. T. Wesselii and T. wyomingensis, on the other hand, are distinguished from each other by stem size and length of internodes. It is unfortunate that Kidston and Gwynne-Vaughan (12) failed to give a more complete account of the cortex of T. Rossica. No mention is made of sclerenchyma in this tissue, although a close inspection of one of their figures (Pl. I, Fig. 4) gives the impression of two sclerotic layers such as occur in T. Wesselii and T. wyomingensis. It is impossible, however, to be certain of this because of the low magnification at which the tissues are shown and the rather inferior preservation that is evident.

When describing species of fossil plants one is perpetually confronted with the problem of how much structural variation to permit to enter into the specific diagnosis or how finely to draw specific distinctions. Accordingly, species are narrowly or broadly interpreted. In describing leaf impressions from the Tertiary the amount of variation that may be encompassed within a species may be judged by the range of variation displayed by the nearest living equivalents. The problem is somewhat different with anatomical material because inside the plant body the range of variation is usually considerably less and, moreover, some species are
much alike so far as vascular anatomy is concerned. It appears, therefore, that constant anatomical differences, even though they may be slight, indicate distinct species. A case in point is demonstrated by T. Wesselii and T. wyomingensis, which have the double band of stone cells in the inner cortex. This relatively inconspicuous feature appears constantly throughout the stems of both species, and in the living condition was no doubt accompanied by distinctive features of the fronds or sporangia which set these apart from others.

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LITERATURE CITED

Fig. 1. *Osmundites oregonensis*, sp. nov. Holotype. Slightly enlarged

Fig. 2. Portion of holotype specimen shown in Figure 1, at a slightly lower level. Enlarged to show the leaf bases. X 3

EXPLANATION OF PLATE I

Fig. 1. *Eorhachis lomarioides*, gen. et sp. nov. Holotype. X 3

Fig. 2. *E. lomarioides*, gen. et sp. nov. Portion of holotype specimen illustrated in Figure 1, showing peripheral bundles and three inversely oriented bundles in the interior. The air spaces in the ground tissue are visible. X 20

EXPLANATION OF PLATE II
**EXPLANATION OF PLATE III**

*Cyathodendron texanum*, gen. et sp. nov. Portion of short stem showing external features. X 1

**EXPLANATION OF PLATE IV**

**Fig. 1.** *Cyathodendron texanum*, gen. et sp. nov. Transverse section of holotype. X 1

**Fig. 2.** *C. texanum*, gen. et sp. nov. Portion of a transverse section, showing the numerous bundles of the medullary region. X 6
EXPLANATION OF PLATE V

Fig. 1. *Cyathodendron texanum*, gen. et sp. nov. Transverse section, showing the outward prolongation of the solenostele to form the troughlike trace strand, and the numerous medullary bundles passing into the petiole. Paratype. X 3

Fig. 2. Section at slightly higher level than that shown in Figure 1. The lower extremity of the compensation tongue appears in the space corresponding to the leaf gap. Holotype. X 2½

Fig. 3. Section slightly above the level shown in Figure 2. The compensation tongue has closed the leaf gap, and the trace has become detached from the solenostele. X 2½

Fig. 4. Section just below point of separation of the petiole from the stem, showing the closed solenostele and the leaf trace of separate bundles. X 2½
Fig. 1. Cyathodendron texanum, gen. et sp. nov. Medullary strand in the central part of the stem. Holotype. X 120

Fig. 2. Portion of the solenostele of the holotype, showing the xylem, the narrow strip of disintegrated phloem, and the sclerenchymatous sheath. X 125

Fig. 3. Portion of the ramentum of multicellular hairs covering the surface between the leaf bases. Holotype. X 80

Fig. 4. Portion of the holotype, showing the tracheids in transverse section. X 475
Fig. 1. *Tempskya Wesselii*, sp. nov. Transverse section of a false stem, from the placer deposits at Greenhorn, Oregon. Paratype. X 1

Fig. 2. Vascular cylinder of a single stem of the specimen shown in Figure 1. X 7

Fig. 1. *Tempskya Wesselii*, sp. nov. Transverse section of two stems embedded within the root mass. From Great Falls, Montana. Holotype. X 9

Fig. 2. Root mass of specimen shown in Figure 1. X 24
EXPLANATION OF PLATE IX

Fig. 1. *Tempskya Wesselii*, sp. nov. Transverse section of stem, showing the three layers of the cortex. Most of the xylem tissue has disappeared. Holotype. X 63

Fig. 2. Portion of the inner cortex of the specimen shown in Figure 1, enlarged to make clear the two bands of stone cells. X 110

EXPLANATION OF PLATE X

Fig. 1. *Tempskya wyomingensis*, sp. nov. Transverse section of the stem, showing two departing traces and a detached petiole (phyllopodium). Holotype. X 6

Fig. 2. Two stems from the holotype, showing departing traces and adventitious roots. X 6
MORE DATA ON DEPRESSION INDIVIDUALITY IN DOUGLAS LAKE, MICHIGAN*

PAUL S. WELCH

In 1928 the writer published a paper dealing with certain limnological features of Douglas Lake, Michigan, in which depression individuality was definitely reported for the first time. Later (Welch and Eggleton, 1932, 1935) more data were added. In the meantime this phenomenon was found in certain multidepression lakes by other investigators. The peculiarly favorable structure of the Douglas Lake basin for this kind of investigation, the recognized importance of limnological researches extended over many seasons, and the challenge of associated problems led to the accumulation of still further data, a certain portion of which is presented here. The previously published data covered eighteen summers. Records for eight other summers are now added, making a total of twenty-six seasons. In no other lake has depression behavior been followed for so long a period. Since this series now seems adequate to exhibit the usual variations and other features of depression individuality in Douglas Lake, the writer expects to discontinue records of this sort except when necessity demands them in connection with other research projects.

The records given in the tables (Tables I-II) attached to this paper are selected from a larger number made during the progress of the work. For the most part the organization of the tables follows that of previous papers in order that comparisons may be facilitated. The field and laboratory methods were essentially those employed in the earlier work except that during recent seasons extensive use was made of a modern, sensitive electrical-resistance thermometer outfit constructed by the Foxboro Company. In all records thermocline limits were determined by the application of Birge's rule.

The results from these last eight seasons, when compared with those of the preceding eighteen, are largely confirmatory. Well-defined individuality in the major depressions is consistently exhibited. Additions to the many details of depression performance have been made, but are of such a nature that they need not be listed here.

During the summers of 1938-42 many vertical temperature records were made from the various depressions on corresponding dates and at very close depth intervals, sometimes as small as 0.1 meter. One purpose of these series was to work out the detailed structure of the thermocline and to discover whether depression individuality extends also to the internal distribution of temperature. These voluminous records cannot be published here, but the principal result may be stated in very brief form. It was found that, when the successive values of fall in temperature from one level to the next lowest are plotted, the differences in internal structure of the thermoclines in the several depressions

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EXPLANATION OF PLATE XI

**FIG. 1.** *Tempskya wyomingensis*, sp. nov. Portion of false stem, showing several stems and petioles embedded within the root mass. Holotype. X 2¼

**FIG. 2.** *T. grandis* Read et Brown. Section showing two or more roots surrounded by a common layer of parenchyma. Root hairs are visible in places. Material from Wheatland County, Montana. No. 23400 Univ. of Mich. Coll. X 25
on the same or similar dates are made visible and easy to compare. From such graphs it is clear that, in addition to features stressed in earlier papers, depression individuality extends also to the internal structure of the thermocline.

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* Contribution from the Biological Station and the Department of Zoology, University of Michigan. This work was facilitated by a grant from the University of Michigan Faculty Research Fund.

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Selections from Papers of the MASAL--Vol. 30 – Page 23 of 61
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**Fairy Island Depression (maximum depth, 28 meters)**

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**Summary of Chemical Analysis**

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**Table 2 (Conclusion)**

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<th>Chl.a (mg/m³)</th>
<th>Surface temp. (°C)</th>
<th>Bottom temp. (°C)</th>
<th>Organisms (mg/m³)</th>
<th>Surface temp. (°C)</th>
<th>Bottom temp. (°C)</th>
<th>pH</th>
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<th>Thermocline (°C)</th>
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A STUDY OF THE SEDIMENT IN DOUGLAS LAKE, CHEBOYGAN COUNTY, MICHIGAN

IRA T. WILSON

IN ORDER to study the sediment in Douglas Lake, located in Cheboygan County, Michigan, one hundred and eleven borings were made to the original bottom of the lake. Since an excellent contour map of the present basin (Fig. 1) was already available, the data secured from the borings were limited to the construction of contour maps of the original basin (Fig. 2), and of a later stage called the "high-level stage" (Fig. 3), and of profile diagrams (Fig. 4), which show the relationship of the original, high-level, and present basins to one another. The contour maps furnished the basis for determining the various morphometrical features (summarized in Table II) of the different basins as wholes and also for the many separate depressions for which the lake is notable.

Most of the borings were exploratory in the sense that they were made rapidly with the intention of discovering only the type of sediment and the depth of the transitional zones between the various kinds of sediment. Nine borings were made, however, in different parts of the lake from which complete cores of sediment were taken. These furnished a careful check on the conclusions based on the exploratory borings and gave material for the study of the chemical and petrographic nature of the sediment and the microfossils and laminations found in it. The fossil pollen from one boring (No. 74 in South Fish-Tail Bay, Fig. 1) has been examined and forms the subject of a paper already published (Wilson and Potzger, 1943). Dr. Ruth Patrick is studying the diatoms and Dr. Frank E. Eggleton the invertebrates from the cores; if the material warrants, they will make separate publications of it. The laminations in the sediment have proved profitable for the construction of a postglacial timetable, which will be the subject of still another paper in the near future.

ACKNOWLEDGMENTS

The major financial support for the field work was provided by the Institute for Fisheries Research, Ann Arbor, Michigan. The Michigan Academy of Science, Arts, and Letters, through grants-in-aid from the American Association for the Advancement of Science, contributed materially to this project. For lodging and laboratory space, shops, boats, and other facilities the writer wishes to thank the Biological Station of the University of Michigan, which is located on Douglas Lake.

The writer is indebted to John McQuate and John H. Thompson, Jr., who helped do the field work during the summer of 1942 and made many of the computations in determining the morphometrical constants, and to Philip Krause and Howard Poetter, who assisted in the field work in 1943. He is very grateful to the staff of the Biological Station for many suggestions and much help, and especially to Dr. A. H. Stockard, who made the arrangements for the work, as well as to Drs. Paul S. Welch, Frank E. Eggleton, Frank C. Gates, and Gerald W. Prescott for suggestions and considerable assistance in the interpretation of the findings. Special acknowledgment of aid is due to Dr. A. S. Hazzard, director of the Institute for Fisheries Research, for his keen interest in the work and for his securing the means to carry it out.

METHODS

The methods used in making the borings and taking the samples of sediment are substantially those described earlier by the writer (Wilson, 1941). He would like to add, however, that he learned that in working from a float on a good-sized lake where the water is rough a considerable part of the time, it is essential to have one as broad as the length of the maximum waves in order to avoid rocking.

A BRIEF HISTORY AND DESCRIPTION OF DOUGLAS LAKE

I. D. Scott (1921) describes Douglas Lake (Fig. 1) as having been "a depression in the bottom of one of the inlets of a great archipelago" during the existence of Lake Algonquin, and says that it became isolated as a separate body of water with the subsidence of the waters of Lake Algonquin. He continues his description as follows:

The separate depressions found in Douglas Lake Scott assumed to be due to irregularities in one block of ice or to several separate blocks left by the melting ice sheet that had previously covered this region. This early period as an embayment of Lake Algonquin is referred to in this report as the Algonquin stage of the lake and the basin it occupied at the outset as the original basin. It was during this early period, according to Scott, that there was developed a broad terrace which still forms a conspicuous feature of the landscape around the lake at approximately the 730-foot elevation above sea level (about 20 feet above the present lake level). If it is assumed that 10 feet of water stood above this terrace when it was cut, then the Algonquin water level would have had an elevation of 740 feet. This is the basis on which the writer used the 740-foot contour (Figs. 1-2) as marking the original shoreline (Algonquin stage) of the lake.
FIG. 1. Contour map of the present basin of Douglas Lake, showing the location of the 111 borings that form the basis of the maps of the original (Fig. 2) and high-level (Fig. 3) basins and the cross-section profiles (Fig. 4). It will be noted that (with few exceptions) the borings have been made along lines that cover the basin in all critical places. The lines are lettered (A-A, B-B, etc.) to correspond with the cross-section profiles in Figure 4. The names of the depressions can be determined by referring to Figure 2. The shoreline of this basin is 710 feet above sea level. The contours are taken from a map the contours of which were made by Dr. Paul S. Welch.

The material surrounding the lake is all of glacial origin and is composed of sand, except at the headlands. These headlands are caused by till, which is much less readily attacked by the waves, and it will be seen from the map (Fig. 42) that, in general, they are opposite each other. There seem to be two small till ridges here which cause the constrictions in the outline of the lake but do not persist across the basin unless possibly in the case of the more westerly. On either side and between the ridges are heavy deposits of sand which partially filled the depressions except where the lake now lies. The eastern end of the lake is surrounded by outwash but the sands of the central and western basins, although possibly outwash, were deposited, in part at least, on the bed of Lake Algonquin which formerly covered this region.

Scott explains that, when the greater Algonquin Lake lowered to the Nipissing level and Douglas Lake became an isolated body of water, the surface of the lake was considerably higher than it is at present and that it was during this high-level stage that most of the shore adjustments were made that characterize the lake today. A broad wave-cut terrace about four feet above the present lake level was developed at this high-level stage. This terrace became exposed when the lake lowered to its present level, and if it is assumed that six feet of water stood above it, then the 720-foot contour can be used to mark the elevation of the water and shoreline for this stage of the lake, as was done in drafting Figures 1 and 3.

Welch (1927) and Welch and Eggleton (1932, 1935) have made special studies of the isolated submerged depressions that occur in Douglas Lake at the present time. There are seven such depressions, known as Fairy Island, Maple Point, Roberts Point, Grapevine Point, Stony Point, Sedge Point, and South Fish-Tail Bay (Fig. 2). The present study has revealed three additional depressions, now completely filled, as having existed in the past; they have been named Bogardus Point, Boys Camp, and North Fish-Tail Bay (Fig. 2). Undoubtedly these newly discovered depressions, like those known to Scott (1921), were caused by stranded blocks of ice from the receding Wisconsin ice sheet. Evidence will be submitted later suggesting that these dead blocks of ice...
remained in the several basins for varying lengths of time and thereby profoundly influenced the distribution of the sediment laid down during the early (Algonquin) stage of the lake.

The pink clay is an amorphous deposit lying below the black mud or marl (warm-water deposits). Data for the shoreline, which is 720 feet above sea level, were taken from a topographical map of the Bogardus tract (southeastern end of the lake) and measurements made by the writer. The dotted part of the shoreline was drawn arbitrarily just outside the present shoreline to form a basis for computing the morphometrical constants of the basin, since at this stage of the lake water covered several square miles of low sandy ground to the west and northwest which it did not seem practicable to include in this study.

**FIG. 3.** Contour map of the high-level stage of Douglas Lake, that is, the basin at the end of the Algonquin stage. The depths were taken from the point of contact of the pink clay (Algonquin deposit) and black mud or marl (warm-water deposits). Data for the shoreline, which is 720 feet above sea level, were taken from a topographical map of the Bogardus tract (southeastern end of the lake) and measurements made by the writer. The dotted part of the shoreline was drawn arbitrarily just outside the present shoreline to form a basis for computing the morphometrical constants of the basin, since at this stage of the lake water covered several square miles of low sandy ground to the west and northwest which it did not seem practicable to include in this study.

**NATURE AND DISTRIBUTION OF THE SEDIMENT**

The sediment in Douglas Lake consists of four types, namely, gelatinous brown to black mud, marl, pink clay, and a brown varved clay. The gelatinous black mud forms the uppermost deposit and is soft for the first few feet, but becomes quite solid farther down and is almost like horn in the bottom reaches. The marl, which lies immediately below the black mud, is gray and rich in carbonates, being quite similar to that found at the surface in some lakes. Both the black mud and the marl are considered to be warm-water deposits (Fig. 4) and to have been laid down after Douglas Lake had become an isolated basin in which the water warmed and stratified in summer much as it does today; this would have been during the high-level and the present stages of the lake.

The pink clay is an amorphous deposit lying below the marl and is thought to have been made during the Algonquin period of the lake and, therefore, to have been a fairly cold-water deposit (Fig. 4). The fact that the water in Lake Algonquin probably had much of its source in the melting ice sheet implies the conclusion given above. The nearly complete lack of organic matter in the pink clay (Table I) and the fact that its color is due to the presence of iron oxide, which probably came from the iron deposits farther north, tend to confirm this interpretation.

The brown varved clay occurs in deposits about a foot thick in several localities in the lake basin below the pink-clay deposit. It was found near the surface at some places near shore, but was present below 104 feet of sediment (172 feet below the present water surface) at boring 2 (Fig. 1) in Fairy Island depression. Since this brown varved clay (often rather thick deposits) occurs over a wide area of this part of the State of Michigan, sometimes at levels higher than Lake Algonquin ever reached (Leverett and Taylor, 1915), it is likely that it antedates Douglas Lake. In Douglas Lake this deposit was always underlain with very fine sand that contains enough carbonates to give a vigorous reaction to hydrochloric acid. There was 41 feet of this fine sand lying under the brown clay at boring 42, below which is coarse gravel. If it should be ascertained that this clay layer is of earlier origin than the Algonquin stage of the lake, it could be utilized as a marker of the original bottom. This would remove some of the doubt expressed by the dotted lines on the map of the original basin (Fig. 2) and, consequently, reduce the volume of the original basin slightly.

That the sequence of deposits is not quite so simple as it appears from the foregoing description and the profile diagrams (Fig. 4), owing principally to the alternation of the various types of sediment at transitional zones between the major deposits, is shown by the following log of a core taken from the center of South Fish-Tail Bay depression: water, 72 feet; soft-flocculent black mud, 72-74 feet; gelatinous-laminated brown mud, 74-103 feet; gray marl, 103-106 feet; tough gelatinous-laminated black mud, 106-107 feet; gray marl, 107-108 feet; pink clay, 108-109 feet; sandy white clay, 109-109.5 feet; white and pink clay layers alternating, 109.5-112.5 feet; fine sand, 112.5-116 feet; sandy pink clay, 116-117 feet; dark-pink clay, 117-123 feet; sand, 123-123.5 feet; pink clay, 123.5-125 feet; sand, 125-126 feet; pink clay, 126-127 feet; sand, 127-127.5 feet; gray clay, 127.5-134 feet; fine sand, 134-135 feet; gray clay, 135-136 feet; fine sand, 136-137 feet; gray clay, 137-138 feet; coarse sand, 138-143 feet.

Table I gives a chemical and petrographic analysis for the four types of sediment listed above, namely, gelatinous black mud, gray marl, pink clay, and brown varved clay. The analyses were made by the laboratories of the Basic Refractories, Inc., of Tiffin, Ohio, to which the writer is indebted. The method of chemical analysis was that ordinarily used with limestone. Miss Elizabeth Haley, of the laboratory, who did the petrographic analyses, found it impossible to separate the material by the usual methods, owing to the large amount of calcite and organic matter present. She says: "No attempt was made to distinguish the various clay minerals — kaolin, dickite, sericite, etc. — and a complete identification of all minerals present was not
undertaken.” The analysis gives a good idea, however, of the relative abundance of the principal minerals. The analysis of the black mud shows it to be mostly water (75 per cent). This is due to its gelatinous nature, because most of this water is an integral part of the jelly and cannot be removed by dehydration with alcohol. A sample taken from nearer the surface would have shown an even higher percentage of water. Exclusive of the water, a large part (30 per cent) of this sediment is organic matter in which pollen grains and fragments of plants can be recognized. Silicon dioxide makes up 48.80 per cent of this sediment (dry weight), which microscopic examination shows to be mostly the tests of diatoms. Quartz, calcite, and limonite were recognized in the petrographic analysis, their importance being in the order given.

The marl sample analyzed, although appearing to be no firmer than the gelatinous sediment, contained only 47.99 per cent of water. On the basis of dry weight there are considerable quantities of organic matter (11.30 per cent) and silicon dioxide (27.20 per cent). The carbonates (mostly calcium and magnesium) form a large proportion of the sediment (approximately 50 per cent), mostly in the form of calcite and dolomite. There was a small quantity of kaolins, also.

**TABLE I**

<table>
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<tr>
<th>Sample composition</th>
<th>Gelatinous black mud</th>
<th>Marl</th>
<th>Pink clay</th>
<th>Brown varved clay (near Burt Lake)</th>
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<td>69</td>
<td>69</td>
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<tr>
<td>Depth below water surface (feet)</td>
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<td>98-99</td>
<td>109-110</td>
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<tr>
<td>SiO₂</td>
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<td>MgO</td>
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**Petrographic analyses**

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<td>Color of dry samples, color after leaching with HCl</td>
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<td>Loss of water on drying</td>
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<td>Zircon</td>
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</table>

* In order of abundance.

By dry weight the pink clay is 48.20 per cent silicon dioxide, nearly all in the form of quartz. The percentage of magnesium oxide is higher than in the marl, and that of calcium oxide is lower; these minerals occur mostly in the form of dolomite. The R₂O₃ compounds are more abundant, probably owing to the increase in aluminum oxide found in the higher proportions of clay and feldspar present. The iron oxide in this sediment undoubtedly accounts for its characteristic pink color. The large amount of clay causes the physical appearance of the sediment. Organic matter constitutes only 1 per cent and, therefore, is almost entirely absent from this material; it is made up to some extent of pollen grains.

The brown varved clay is much like the pink clay, except that considerable calcite as well as limonite is present; the limonite accounts for the brown color. The number of varves ranges from 10 to 30 per inch, and they indicate that the deposit was laid down in cold water, since they do not form in water over 10 degrees centigrade.

The distribution of the warm- and the cold-water types of sediment is indicated on the profile drawings (Fig. 4).
The black shaded portions of the profiles represent the gelatinous black mud and the marl; the marl makes up only a few feet of this part of the deposit near the bottom. The crosshatched portion of the profiles indicates the pink-clay deposit. By means of graphs, Figure 5 gives a good idea of the distribution of the sediment in the various separate depressions and in the lake as a whole.

Morphometrical Changes in the Basins

1. Introduction

Reference has been made to the fact that Douglas Lake has passed through three stages, namely, (1) the Algonquin, at which time it formed an embayment in the great postglacial Lake Algonquin, (2) the high-level stage, which began when Lake Algonquin receded to the Nipissing level and isolated the Douglas Lake embayment, and (3) the present stage, which is approximately ten feet lower than the high-level stage. There is no way to distinguish between the sedimentary deposits laid down during the high-level and the present stages; consequently the comparisons between stages are between the basins of the beginning of the Algonquin stage (original basin), of the beginning of the high-level stage (high-level basin), and of today. At the west end of the lake the study of the morphometry of the original and high-level basins has been restricted to the region of the present basin, in spite of the existence of a broad contiguous plain extending several miles beyond that was covered with water during the Algonquin and high-level stages. The character of the deposit over this plain indicates that it resulted more from forces within the main body of Lake Algonquin than from the forces prevailing within the embayment that subsequently formed Douglas Lake.

In this section of the report four things will be described: (1) the three stages of each depression (with a comparison of similar morphometrical features included); (2) the three stages of the lake as a whole; (3) certain boulder belts; and (4) unusual sand deposits found in some depressions. The morphometrical data for all the depressions and for the lake as a whole are tabulated in Table II, together with the percentages of change that took place between the stages. It should be kept in mind that in the morphometrical computations each depression was considered as if the topmost complete contour (isolation contour) were its shoreline and marked the surface level of the depression. Obviously, from this point of view, all the depressions were submerged many feet below the general surface water of the lake and, consequently, were removed from the influences of wave action. No other way to work out the morphometrical features for purposes of comparison seemed feasible.

2. Descriptions of the Depressions and Comparison of the Morphometrical Features of the Three Stages

Fairy Island depression. — This depression (Figs. 1-3) is by far the largest of all the depressions in Douglas Lake at all three stages, as is indicated by the areas at the various isolation contours (60 feet for the original basin; 50 feet for the high-level; and 40 feet for the present basin). The original Fairy Island depression has an area of 27,590,000 sq. ft., the high-level stage 9,063,000 sq. ft., and the present basin 7,042,000 sq. ft. This is a decrease of 67.15 per cent from the original to the high-level stage and of 22.30 per cent from the high-level to the present stage. Such a marked decrease in area from the original to the high-level basins indicates a tremendous accumulation of sediment around the periphery of the basin during the Algonquin stage.

The data given above and all other data referred to in this section will be found in tabular form in Table II.

The maximum depth of Fairy Island depression increased from 141 to 143 feet from the original to the high-level stage and the mean depth from 46.44 to 69.35 feet, which shows that scarcely any of the sediment settled in the center of the basin during Algonquin time. In great contrast there was a decrease of 66.72 per cent (from 69.35 to 23.08 feet) in mean depth after the beginning of the high-level stage; these changes, together with the rather small decrease in area (22.30 per cent), indicate that practically all the sediment settled in the center of the basin during this time. By looking at the graph (Fig. 5) the changes noted above can be visualized.

The reduction in volume from the original (1,281,430,000 cu. ft.) to the high-level (628,599,000 cu. ft.) stage was 50.94 per cent as contrasted with a reduction of 74.14 per cent from the high-level to the present stage (162,567,000 cu. ft.). The absolute amounts of the reductions in volume were 652,831,000 and 466,032,000 cu. ft., respectively.

In view of the contrasting changes in area and maximum and mean depths during the Algonquin and subsequent stages of the lake, it is not surprising to find that the mean slope increased from 5.19 to 11.95 per cent during the former period and decreased from 11.95 to 5.92 per cent during the latter one.

There was an increase in volume development of 40.00 per cent from the original (1.0) to the high-level (1.4) basins. In contrast to this there was no change from the high-level (1.4) to the present (1.4) basins.

The length of the shoreline decreased from the original (21,250 feet) to the high-level (11,750 feet) basin by 44.70 per cent but increased by 13.19 per cent from the high-level to the present (13,300 feet) basin. Shore development did not change during the Algonquin stage but increased 27.27 per cent (1.1 to 1.4) during the subsequent period. These figures are significant so far as the original to high-level changes are concerned, but
are not so dependable in comparing the high-level to the present basin because the "shoreline" (isolation contour) of the present basin was determined from so many more soundings than those of the other two basins were that it shows many irregularities overlooked in the two earlier basins.

The volume of sediment (Table III) laid down during the Algonquin stage was 836,101,000 cu. ft. and that laid down subsequently, that is, since the beginning of the high-level stage, is 546,560,000 cu. ft. Comparison of tables giving the volume of sediment by frusta (on file at the office of the Institute for Fisheries Research) shows that 50 per cent of the sediment laid down during the Algonquin stage lies above the base of the third frustum (30-foot contour), whereas 50 per cent of that deposited afterward (high-level and present stages) lies above the base of the sixth frustum (60-foot contour). This difference follows from the fact that most of the sediment was laid down in the shallow periphery of the basin during the Algonquin stage but in the center during the later stages.

Maple Point and Grapevine Point depressions. — These two depressions resemble Fairy Island depression in that most of the pink-clay sediment characteristic of the Algonquin period of the lake settled around the periphery of the basin, whereas the reverse process (filling in the center) prevailed during the high-level and the present stages of the lake. This sequence of filling caused changes in the morphometrical features, from the original to the high-level stage on the one hand and from the high-level to the present stage on the other, to be about the same as those for the corresponding periods in Fairy Island depression. These resemblances can be verified by consulting Table II. Figure 5 shows the similarities graphically.

The three basins described so far, namely, Fairy Island, Maple Point, and Grapevine Point, were the largest and had the greatest maximum depth and volume of all the ten depressions in the original basin of Douglas Lake. They must have been formed by the largest blocks of ice. Their size, as will be shown later, probably is responsible for the peculiar manner in which they were filled as contrasted with that of the other basins.

Bogardus Point depression. — This depression differs radically from those already described in that it was almost completely filled with pink clay during the Algonquin stage of the lake. The difference is reflected to some extent in changes that have taken place in morphometrical features (Table II). During the Algonquin stage sediment settled in the center more rapidly than around the periphery (Fig. 5) and thus caused a reduction in maximum depth from 64 feet in the original basin to 11 feet in the high-level basin and a