SOME ILLINOIS OZARK FERNS IN RELATION TO SOIL ACIDITY.

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This ecological study of ferns, relative to soil conditions, slope, rock face, plant associations and nature of underlying strata was undertaken under the direction and inspiration given by Dr. H. C. Cowles, during his visits to the Southern Illinois Ozarks. It was pursued during the course of two years, and the data on soil acidity was taken during two summer and fall seasons.

The region selected is especially suited for this study because it furnishes a great range of radiant, physiographic and geological features. These give rise to a variety of light, soil, slope, rock face and temperature. It is a region located mostly along the northern slope of the Southern Illinois Ozarks, south of a line running east and west through Carbondale, Illinois. It dips into Union County, including Alto Pass, Bald Knob and Giant City; and into Johnson County, including Ferne Clyffe and Benson Bluff. The remainder of the region is included in Jackson County. From east to west it extends about thirty-six miles, the width from north to south is nearly twenty-four. Its area is a little less than six-hundred square miles, and approaches the size of Jackson County.

Although there are a number of fern locations in this territory, the extent of the area is so small that these all belong to one geographical unit. The ferns studied are all native to the region. The factors that will be considered are climate, rainfall, light, shade, geological composition of rock, Physiographic features and nature of the soil with respect to acidity.

Only weather conditions and soil acidity have been quantitively studied.

The meterological data are taken from the records of the station at Carbondale, (4) which is the nearest one to the area as a whole. In a period of ten years there were but two years when the summer temperature did not reach one hundred degrees Fahrenheit, or above.

During these two it lacked but two degrees of the one hundred mark. The average maximum for the ten years is almost exactly one hundred. There were four years when the minimum did not reach zero. The average is exactly zero for the coldest days. In the winters of 1912 and 1918 the temperature reached minus twenty-four and minus eighteen degrees respectively. The average mean July temperature for the last ten years is 80.04°. The average date of the first killing frost of fall is October twenty-fifth. The average date of the last killing frost of spring is April ninth. This gives an average period free from frosts of six months and sixteen days.

The rainfall of the region is the heaviest in the state, and has ranged from forty-four to forty-five inches for ten years. For Carbondale the average is forty-four inches, for some of the higher slopes it averages forty-five inches for ten years. The average distribution of rainfall by months is quite uniform, with a slight maximum in March, June, and November; and a minimum in August, September and October. In the summer months the amount sometimes falls low. For instance, in 1914 only ninety-two hundredths inches fell in June and thirty-five hundredths inches fell in July, making in all, for a period of two vegetatively important months, a rainfall of but one and twenty-seven hundredths inches. The mean monthly temperature for July of that year was eighty-three degrees, or three degrees above normal. Again in 1916 the rainfall in July was only twenty-one hundredths inches, while the mean temperature for the time was eighty-two degrees, two degrees above the average.

It is not, however, the mean temperatures and average rainfall, nor the average date of killing frosts that are the telling features of the vegetative species found, but the extremes of these that are the decisive things in the control of species in any locality. To illustrate with a critical temperature: A region whose average minimum temperature is just above freezing, will run sometimes above, sometimes below the freezing point, and thus all plants that can not endure frosts will be driven out. Such a region could not grow tropical plants, although such plants might live there for a few winters. On the other hand, to illustrate with a temperature not critical: A region whose temperature has an average maximum of one hundred, might run often enough to one hundred five or six to kill out plants which might possibly endure an occasional temperature of one hundred degrees. So this region which sometimes ranges to one hundred four degrees maximum, and to minus twenty-four, minimum, has a range of almost one hundred thirty degrees temperature. Plants not able to endure this range of temperature would be driven out, or found only in occasional, well protected areas.

The species found in the region are: (10), (2), (1).

#1 Polypodium vulgare, L., common polypody.
#2 Polypodium polypodioides, (L), resurrection fern.
3 Phegopteris hexagonoptera, (Michx), Fee., broad beech fern.
4 Adiantum pedatum, L., maiden hair fern.
5 Pteris aquilina, L., commonbrake, or bracken.
#6 Cheilanthes lanosa, (Michx) Watt., hairy lip-fern.
#7 Cheilanthes feei, Moore.
#8 Pellaea atropurpurea, (L) Link, purple cliff brake.
#9 Asplenium pinnatifidum, Nutt, pinnatifid spleenwort.
#10 Asplenium trichomanes, L.
#11 Asplenium parvulum, Mart. & Gal.
#12 Asplenium platyneuron, (L) Oakes, ebony spleenwort.
13 Asplenium angustifolium, Michx, narrow leafed spleenwort.
14 Asplenium acrosticoides, Sw., silvery spleenwort.
15 Asplenium filix-femina, (L) Bernh, lady fern.
#16 Camptosorus rhizophyllus, (L) Link, walking-leaf fern.
#17 Polystichum acrostichoides (Michx) Schott., Christmas fern.
#18 Polystichum acrostichoides, var. Schweinitzii.
#19 Aspidium marginale (L) Sw., evergreen shield fern.
#20 Aspidium spinulosum, var. intermedium (Muhl) D. C. Eaton, spinulose wood fern.
21 Cystopteris bulbifera (L) Bernh., bulblet bladder fern.
22 Cystopteris fragilis (L) Bernh., fragile bladder fern.
23 Woodsia obtusa (Spreng) Torr, blunt lobed woodsia.
24 Onoclea sensibilis L., sensitive fern.
25 Osmumda cinnamomea, L., cinnamon fern.
26 Botrychium virginianum, (L) Sw., grape, or rattlesnake fern.

In Union County ferns have been studied and listed by C. M. Wright, in Jackson County by G. H. French. Wright in Union County showed nothing different. French in Jackson County has listed three ferns not included in the above, as follows:

1. Botrychium ternatum, (Thumb) Sw., ternate grape fern. This fern is probably in Jackson County, but has not been found in the areas studied. It is found in more open woods and pastures.

2. Osmunda regalis L. flowering or royal fern. This was found but once by Mr. French, in a shady nook, by a railroad pond, near Bosky Dell, where the railroad cuts off a bend in Drury Creek.

3. Asplenium ebenoides, R. R. Scott, Scott asplenium. This was found but once, near Ava, by Mr. John Marten, a number of years ago. The single specimen was identified by Dr. Asa Gray as Asplenium ebenoides. It was destroyed by the fire which burned the Normal building, Nov. 26, 1883.

There are four species in this collection not collected by either Wright or French, as follows:

1. Asplenium acrosticoides Sw., found abundantly in the ravines of Big Hill and Bald Knob, always in association with A. angustifolium and A. filix-foemina, and intermediate between them.

2. Polystichum acrostichoides, var. Schweinitzii, found in association with the above spleenworts, and its near relative, P. acrostichoides. It almost supplemented the latter on the limestone talus of Grand Tower and Bald Knob.

3. Asplenium parvulum, found only on the limestone at Bald Knob and near Grand Tower, growing either in the crevices of the limestone, or on the rich mold covering them.

4. Osmunda cinnamomea, found but once, and then in a cool easterly facing beech-wood ravine on the east side of Bald Knob. It was found in association with the three Aspleniums mentioned under 1, with Phegopteris hexagonoptera and Adiantum pedatum.

Of the twenty-six ferns listed, fourteen are evergreen, (indicated by the check in the left margin). These consist of two Polypodiums, four Aspleniums, two Polystichums, two Cheilanthes, two Aspidiums, Camptosorus rhizophyllus and Pellaea atropurpurea. This means that the vegetative structure of these ferns is such as will endure 104° heat in summer, and —24° in winter, or a temperature range of 128°. It means also that they will endure the hydrophytic conditions of spring and fall, equivalent to forty-five inches of rainfall, and between these seasons endure two abnormally hot months of drought with but the total of one and one-fourth inches of rainfall. This doubtless explains why Asplenium ebenoides, a southern species, and the two Osmundas which are northern species are found here but once. This will be discussed later.

On account of their close relation, the geology and the physiographical features of the region can best be taken together. (6).

Geologically this region belongs to that "Island uplift" (5), "once surrounded by ancient seas." Its structure includes a wide range of formations, embracing an aggregate thickness of more than three thousand feet. It ranges from the top of the lower coal measures down through the Pottsville sandstone, Mississippian limestones, Devonian chert and limestones almost to the Upper Silurian limestones. (See physiographical map of the region Plate I.) Its choice for study is based on this variety in the formation.

There are two general types of exposure. The Pennsylvanian sandstone and conglomerate outcrop of the north and northeastern portin, and the Mississippian and Devonian limestones outcropping to the south and southwest. The first type is of quartzose sandstone and conglomerate of the lower Carboniferous series. It underlies the region beginning just north of Carbondale, at an elevation of 350 feet, and sloping gradually up the Ozarks to an altitude of between six and eight hundred feet, where it outcrops in precipitous cliffs. Alto Pass, the highest railroad station in Illinois, 738 feet, stands at the edge of this outcrop. (9) In Johnson County it reaches about the same height as at Alto Pass, (7) but where the Illinois Central cuts through, half way between these two points, the outcrop reaches only about six hundred feet. (8) This slope is dissected by streams that run northeastward to empty into Big Muddy River. This stream encircles most of the region on the north and west, emptying into the Mississippi below Grand Tower. The southern edge and front of this slope is dissected by other streams, that have eaten their way across the limestone crest, and are now taking their toll from its sandstone face and banking it in the deposits of Cache, Big Cypress and Clear Creeks. (7) Besides this water dissection, this slope shows at places evidence of some great crustal disturbance, as the great perpendicular passage-ways at Giant City, near the boundary between Jackson and Union Counties. (5)

Benson Bluff is the Sandstone face in Johnson County.

Ferne Clyffe in Johnson and Fountain Bluff in Jackson County represent two unique but different types of erosion and dissection in this stone. At Ferne Clyffe about five acres of land seems to have eroded down to a base of more than one hundred feet below the general level of the surrounding region, leaving a circular wall of rock. Here, especially on the north and northeast facing cliffs, true to its name, the rocks furnish the environment for crowds of ferns and their associates.

At Fountain Bluff (8) in contrast, ten to twelve square miles of arenaceous rock stands out three to five hundred feet above the plain of the Mississippi bottom land, like a giant table spread with a cloth of loess and chert. This is the exact converse of the smaller formation at Ferne Clyffe. Here, too, on the north facing cliffs are found nearly every type of rock fern found in Southern Illinois. These two regions, topographically so different, furnish similar environmental conditions for plant growth.

All the outcrops of this general type of formation consist of what geologists call Pottsville sandstone. It is popularly known as millstone grit. The face of the rock is sometimes white, sometimes it is colored with ferruginous matter which wears unevenly, leaving gnarled and turbinated dark brown projections from the face of the rock. These furnish shelves, crannies and foot-holds along the bluff for the plants to take root.

The second general type is a limestone outcrop. It is exposed by the Ozark uplift and denuded by the heavy rainfall, coupled with precipitous slopes inclining from twenty-five to forty-five degrees. The trend is from northwest to southeast. It is below yet above the sandstone face. The tops rise to an altitude of more than a thousand feet above sea level, and slope southward, in a few miles reach down to within about three hundred feet above. In many places it has a perpendicular distance of more than half this descent. The Mississippi River and its flood plain bound it on the west, it reaches beyond the region studied to the Ohio River on the east. Its physiographic features are combinations of uplift, erosion and faulting. One great fault line beginning near Grand Tower on the Mississippi, extends nearly to Pulaski County in a southeasterly direction. It has been suggested by Weller that the entire uplift may be due to the eastward extension of this fault. (5) The down throw of this fault is on the northern side, which has made it possible for the rocks south of it to be eroded down to lower levels, and it is here that we see exposed The Silurian and Ordovician stones, which are not outcropping anywhere else in the state.

At the Bake Oven and Devil's Back Bone on the Mississippi are representative rock exposures of this type. They front toward the Mississippi River and dip toward the northeast at an angle of twenty-five degrees. They consist of cherty, siliceous, foetid limestones, extending one hundred to two hundred feet above the flood plain of the river. Their summits for about thirty feet belong to the lower Mississippian limestone. Below this the formation is probably Devonian.

About eight miles to the southeast, conspicuous for many miles in all directions, are the summits of five hills covered with woodlands except that of the tallest, which on this account is called Bald Knob. The last, having an altitude of one thousand twenty-five feet, is the tallest peak of the Mississippi River Ozarks. Its summit is composed chiefly of siliceous limestones and chert formations. Cherty beds outcrop along its lower slopes, while on its sides are seen masses of tumbling quartzose sandstone. According to Worthen, these sandstones appear to belong to the Devonian layer just above the Oriskany series. They readily yield to atmospheric influence. The top of Bald Knob is so covered with detritus that its nature is hard to determine, but where the effort to find gold has cut several feet below the surface, it reveals the Oriskany chert not many feet below. This hill is greatly dissected by erosion, furnishing numerous ravines and rock faces.

Four miles east of Bald Knob is a narrow valley with the shales and limestones of the lower Mississippian limestone exposed on each side. This is known as Mountain Glen, and furnishes the fourth limestone area of this study. It together with the Bake Oven, Back Bone and Bald Knob constitute the group of limestone areas especially chosen as furnishing suitable environment for the study of both rock and soil ferns.

The best sandstone areas found for the study were Makanda, (Stonefort and Giant City), Fountain Bluff, Ferne Clyffe and Benson Bluff. The areas are all marked on the map, enclosed by single dotted lines to indicate limestone, and double dotted lines to indicate the sandstone areas.

As nearly as possible similar areas were chosen from each portion, and localities selected where the ferns grew best. In climate and rainfall all areas are practically the same. In topography, sunlight and surface moisture conditions, Ferne Clyffe and Mountain Glenn are very much alike; both are areas of depression, surrounded by bluffs, with a perpetual flow of water through the lowland, and a natural growth of forest in the valley and on the tops of the bluff above. Both present rock face for the rock ferns and rich forest mold for the soil ferns. The only distinguishable difference lies in the nature of the rock itself.

Likewise the deep ravines and wooded slopes of Big Bluff are very like those of Bald Knob, while its rocky face is similar to that of the west and northwest face of the Bake Oven and Back Bone. The Makanda outcrops and Benson Bluff have their counterpart in the limestone cliffs of the ridge of Back Bone and in the bluffs along the Alto road north of Bald Knob.

This seemed an excellent opportunity to compare the "calciphils" and "calciphobes" of Unger, or better, to determine what distinction there may be between the calcicoles and the silicicoles of later writers.

The ferns from each area were first collected, identified and listed by regions. This is found in Table I, Page 12.

These same ferns were again listed with their habitat according to Gray's Manual. This list is found in Table II, Page 13.

After this study of the ecology of Southern Illinois ferns was begun, the American Fern Journal and the Smithsonian Report 1920, published articles by E. T. Wherry, giving results of fern studies in New England, and in the Virginias. These were studied in relation to soil acidity, and the comparisons made between the northern and southern ferns in this respect were very interesting.

Wherry says: "The calcareous soil species prove to be dominantly northern. This is connected with their

TABLE I.

Ferns Listed by Regions.

	Back-Bone.	Bake Oven.	Mt. Glen.	Bald Knob.	Giant City.	Benson Bluff.	Fern Cliff.	Ft. Bluff.
Rock Ferns:								
Asplenium parvulum	x	x		x				
Cheilanthes Feei	x	x						
Pellaea atropurpurea	x	x						
Polypodium vulgare				x	x	x	x	x
Polypodium polypodioides					x	x	x	x
Asplenium pinnatifidum					x	x	x	x
Cystopteris bulbifera	x	x			x	x	x	x
Asplenium trichomanes		x		x	x	x	x	x
Woodsia obtusa	x	x	x	x	x	x	x	x
Asplenium platyneuron	x		x	x	x	x	x	x
Cystopteris fragilis	x	x	x	x	x	x	x	x
Cheilanthes lanosa		x			x	x	x	x
Camptosorus rhizophyllus	x		x	x	x	x	x	x
Soil Ferns:								
Aspidium marginale					x	x	x	x
Polystichum acrostichoides	x		x	x	x	x	x	x
Polystichum acrostichoides var. Schweinitzii	x		x	x	x			x
Asplenium spinulosum var. intermedium					x	x	x	
Pteris aquilina					x			x
Osmunda cinnamomea				x				
Adiantum pedatum	x		x	x	x	x	x	x
Botrychium virginianum	x	x	x	x	x	x	x	x
Phegopteris hexagonoptera	x		x	x	x	x	x	x
Asplenium acrostichoides				x		x		x
Asplenium filix-femina			x	x	x	x	x	x
Asplenium angustifolium				x				x
Onoclea sensibilis				x			x	x

TABLE II.

Fern Habitat and Range as Listed by Gray.

Name of Species.	Habitat.	Range.
Rock Ferns:		
Asplenium parvulum	Mountains	Va., Kan. and Sw.
Cheilanthes Feei	Dense tufts, dry rocks and cliffs	Ill., Minn. W. and Sw.
Pellaea atropurpurea	*Dry* calcareous rocks	N. H., R. E., Ga. and Ww.
Polypodium vulgare	Rocks	Common.
Polypodium polypodioides	Rocks and tree trunks	Va., O., Ia. and Sw.
Asplenium pinnatifidum	On cliffs and rocks	Ct., Mo. and Sw., Rare.
Cystopteris bulbifera	Shady ravines, chiefly calcareous rocks	
Asplenium trichomanes	Shaded rocks	Widely distributed.
Woodsia obtusa	Rocky banks and cliffs	Me., Ga. and Ww.
Asplenium platyneuron	Rocky open woods	Me., Col. and Sw.
Cystopteris fragilis	Shaded cliffs, rocky woods	Common.
Cheilanthes lanosa	Clefts of rocks	Ct., Minn. and Ww.
Camptosorus rhizophyllus	Shaded, especially calcareous rocks	Me. and Minn., Sw. to Kan. and Ga.
Soil ferns:		
Aspidium marginale	Rocky hillsides in rich woods	Common, especially Northward.
Polystichum acrostichoides	Rocky woods	Common.
P. acros. var, Schweinitzii		Not rare.
Asplenium spinulosum, var. intermedium	Woods	Common.
Pteris aquilina	Thickets and hillsides	Common.
Osmunda cinnamomea	Swamps and low copses	Common.
Adiantum pedatum	Rich, moist woods	
Botrychium virginianum	Rich woods	Common.
Phegopteris hexagonoptera	Rather open wood	Me., Minn. and Sw.
Asplenium acrostichoides	Rich woods	N. S., Minn. to Ga. and Ala., not rare.
Asplenium filix-femina	Moist woods	Common.
Asplenium angustifolium	Rich woods	N. H., Minn. and Sw.
Onoclea sensibilis	Moist meadows and thickets, etc.	Very common.

evolutionary history." "The rock ferns are more sensitive to soil acidity than the soil ferns." "The peculiar relations of favoring of acid soils by southern species and circumneutral by northern ones appear to hold in other plants than ferns." He urged other workers to make similar studies in other sections for comparison with his results.

The isotherms of Southern Illinois were then studied and compared with those of the Virginia region. (See map, page 15.) As for latitude the two regions are practically on the same parallel (20). As for temperature, the isotherms of Southern Illinois cover the Virginian region with one striking exception. The spring and fall temperatures run about the same. In the winter months of January and February Southern Illinois runs a few degrees colder. The striking exception is in summer. In the month of July, the hottest and driest for Illinois, its isotherm dips down into Tennessee and South Carolina, while the Virginia isotherm runs almost to the Chicago temperature. The average maximum for Southern Illinois for the last ten years, is one hundred degrees, that of Chicago for the same time is eighty degrees, a difference of twenty degrees, in the month when excessive transpiration is the plant's greatest enemy. This one difference may serve as a clue to a contested ecological problem i. e. the relation of certain plants to a calcareous habitat.

Because of the interest in Wherry's problem, the separation into rock and soil ferns in this paper has followed his division (3). Had Gray's Manual been used for this division of habitat, the lines would have been the same, with the addition to rock ferns of the two Polystichums and Aspidium marginale. The latter division would better have suited the fern habitats of Southern Illinois. Here one more fern should be added, Aspidium spinulosum. This means that in the section studied seventeen out of the twenty-six ferns are tied up in their relation to the rocks. Yet in Southern Illinois Woodsia obtusa and Cystopteris fragilis might be classified as soil ferns since they grow most abundantly in the forest, low on the talus slopes.

There are but three ferns found exclusively on the limestone areas. They are Asplenium parvulum, Chcilanthes Feei and Pellaea atropurpurea. It is probably

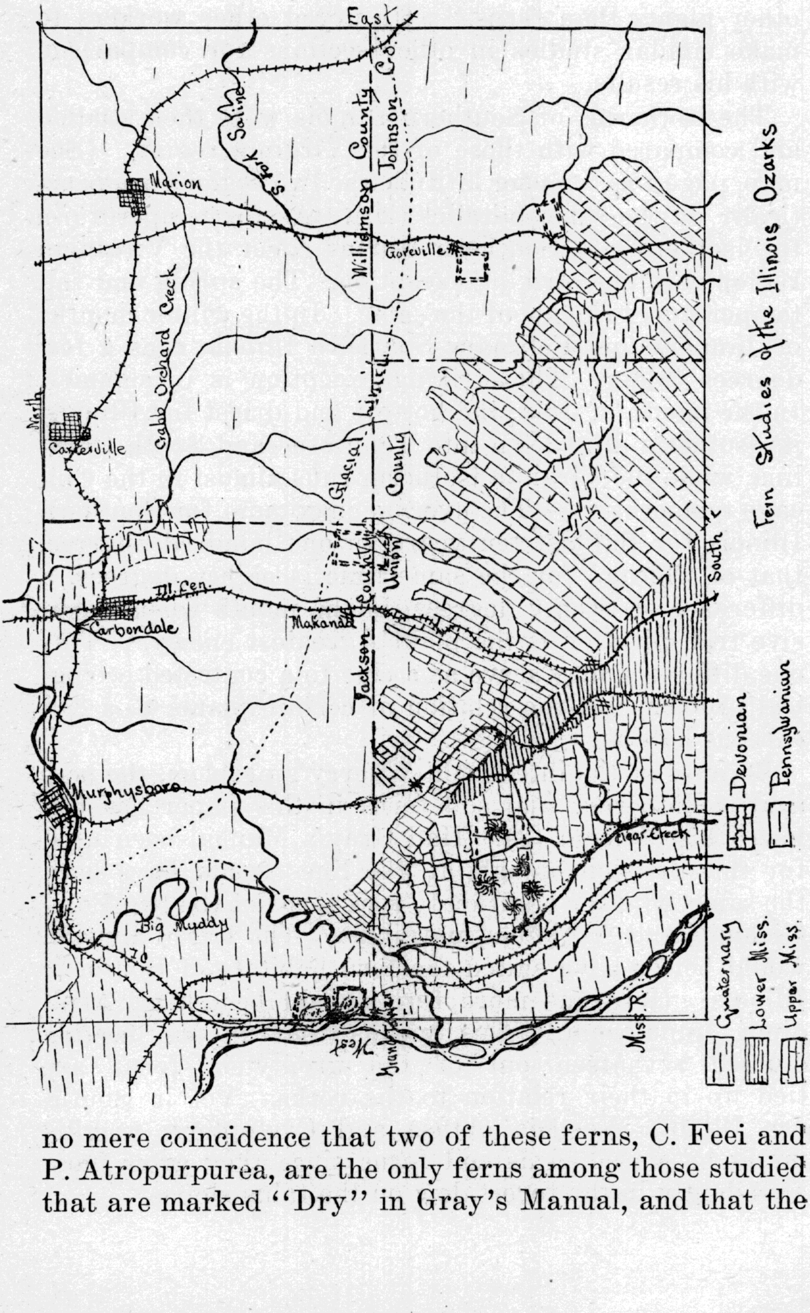

Plate I.

no mere coincidence that two of these ferns, C. Feei and P. Atropurpurea, are the only ferns among those studied that are marked "Dry" in Gray's Manual, and that the third A. parvulum is indicated as a mountain species. This no doubt means that of the twenty-six ferns of the area, these three are the most noticeably xerophytic. Why should the three most xerophytic ferns be tied up with the limestones? What relation can xerophytism have to a calcicole habitat?

It is a known fact that wet soils may be made drier by the addition of limestone. In the first place lime has a slight chemical or physical affinity for water and imbibes a small portion of it as it is freed from its combination with its rock compound. In the second place lime has the power of destroying the colloidal property of clayey soils, rendering them flocculent, and consequently less capable of holding water (18) (19).

In a region where the two mid-summer months are such as has already been indicated by the weather report given for Southern Illinois, this difference in ability of the soil to have, and to hold water during the months when the rainfall is often less than an inch per month means a summer vegetative condition very different on limestone as a medium compared with a sandstone medium. Other things being equal, we should expect under such conditions, only the most xerophytic plants to be able to live on the limestone. Then Wherry should be right in saying that this peculiar relation appears to hold in other plants than ferns (3). This condition drives out the Hepatica, the phlox, even the Heuchera and vaccinium from our limestone cliffs, and leaves as the dominant things, the Solidago and the Juniperus virginiana. These both speak loudly of extreme xerophytism.

The above applies chiefly to the rock face, or to places where the flinty rock breccia constitutes the greater part of the soil. This breccia is particularly noticeable about such arenaceous limestone outcrops as those of the Back Bone, Bake Oven and Bald Knob. But in the wooded ravines where the vegetation has the advantage of fifty to one hundred feet of immediate slope with its seepage, where the heat rays are reduced by the angle of incidence, and moisture is held by the roots and leaf mold, the difference between a limestone and a sandstone area is greatly reduced, and we again agree with Wherry in saying: "Ferns of woods and swamps are less sensitive to soil acidity than rock ferns (3). This will be discussed later when the tables showing the result of the soil tests for acidity have been introduced.

We have called the ferns of the calcareous rock very xerophytic. In what ways they indicate this can best be shown by comparison with the forms found exclusively on the sandstone. These ferns are Asplenium pinnatifidum, Polypodium polypodioides and Polypodium vulgare. The last named was checked for the Bald Knob area; but it was not on the limestone there. It was found only on those blocks of quartzose sandstone, referred to above as being weathered from the Devonian layer above the Oriskany group. Though checked for the area it belongs exclusively to the siliceous rock. These are the so-called "Acid ferns", or silicicoles.

In order to arrive at a way of measuring what is supposed to be the fundamental difference between calcareous and siliceous soils, the La Motte Indicator was sent for. As it did not arrive in time for the spring work, the Grindley test, used by the University of Illinois for making practical soil tests was employed. It is a color indicator, but does not express the hydrogen ion concentration, nor is it supposed to show the degree of acidity. It consists of a weak solution, 5-6%, KCN in 95% ethyl alcohol. Tests were made in the following way:

Small vials were chemically cleaned, and provided with corks and labels. Adhesive tape was found to be the most serviceable for labeling, as it did not come off, and once on could be washed with the bottle. These and the KCN solution were carried into the field. By experimentation with the solution it was found that a very slight acidity produced a very light pink color, while a decided acidity gave a red color. This was made use of in recording results. In the field the bottle was half filled with the soil from near the plant root, the bottle was labeled, tightly corked and placed in the vasculum. When rest time came, the bottles were filled two-thirds full of the solution, and thoroughly shaken, then allowed to stand until the sediment settled. The results were tabulated in three categories, as shown in Table III, page 19. Those showing no sign of color were the neutrals and marked with an "O". Those showing just a tinge of pink were marked with an "s". Those showing a decided red color were marked with an "a". The same division of Rock and Soil Ferns as was previously used is adhered to.

This work was done in May and June, 1922. Soil tests were made for all the ferns for each area, and many tests for each species of the area, but as the tests are not quantative, only the summary of results from all areas is indicated in the table. Where a species shows different results from different areas, this is indicated by placing after it the two or three letters indicating this, and underscoring the letter indicating where the maximum of results lay.

The results show:

(a) Three of the rock ferns and four of the soil ferns are unquestionably neutral.

(b) Four of the rock ferns and two of the soil ferns are decidedly acid. (These two soil ferns are two of those that should from their Southern Illinois habitat be classed as rock ferns.

(c) Of the rest, three of the rock ferns are found growing in all three of the habitats. Only one of the soil ferns shows this range, and it is one of those belonging rather to the rocks than to the soil in this section. Two of the remaining rock forms are found in two habitats, as are also two of the soil ferns, but one of those is another rock form here.

(d) This indicates that the range of the rock forms as to acidity is greater than that of the soil forms.

In September, 1922, the La Motte Indicators were used and the entire field covered again with the exception of Benson Bluff. These indicators show a certain degree of hydrogenion concentration, and were used in the field as were the others. Their use is described in Ecology I, pp. 160-173, and is so well known as to need no description here. The bottles and corks were kept chemically clean, the water used was distilled and always tested for neutrality before using. When possible the tests were made the day the samples were collected. No tests were made from herbarium material. The number of tests are indicated in Table IV.

The results are recorded as suggested by Wherry in the Smithsonian Report, 1920, with maximums in full-face type. Range is indicated by x's, the smaller ones indicate but one or two in the range, the larger ones, several. The rock and soil ferns are in different tables. Each group is arranged according to the degree of acidity bginning with the subalkaline.

There are eight degrees of specific acidity shown, viz., 300, 100, 30, 10, 3, 1, 3, 10. The rock ferns run through them all. The soil ferns omit the highest, 300. Note also that the maximum in the rock ferns range through the entire eight grades of specific acidity, the soil ferns through but four.

In specific acidities pure water which has equivalent amounts of acid and alkaline constituents, ions, is termed 1, or neutral, and taken as the unit of both specific acidity and specific alkalinity. A solution containing up to 10 times as much acid as is contained in pure water is called minimacid; one containing from 10 to 100 times, is called subacid; from 100 to 1,000 times, mediacid; more than 1,000 times, superacid. Corresponding terms are used on the alkaline side. Minimacid, neutral and minimalkaline are grouped together as circumneutral.

TABLE III.

Grindley Tests.

	Neutral.	Media-acid.	Acid.	Maxi-mum.
Rock Ferns:				
Asplenium parvulum	O	....	....	O
Cheilanthes Feei	O	....	....	O
Pellaea atropurpurea	O	....	....	O
Asplenium trichomanes	O	s	....	O
Asplenium platyneuron	O	s	....	O
Cystopteris fragilis	O	s	a	S
Camptosorus rhizophyllus	O	s	a	S
Cystopteris bulbifera	....	s	....	S
Woodsia obtusa	O	s	a	S
Cheilanthes lanosa	....	....	a	A
Asplenium pinnatifidum	....	....	a	A
Polypodium vulgare	....	....	a	A
Polypodium polypodioides	....	....	a	A
Soil Ferns:				
Osmunda cinnamomea	O	....	....	O
Adiantum pedatum	O	....	....	O
Phegopteris hexagonoptera	O	....	....	O
Asplenium angustifolium	O	....	....	O
P. acros. var. Schweinitzii	O	s	....	O
Botrychium virginianum	O	....	a	S
Asplenium acrostichoides	O	s	....	S
Onoclea sensibilis	....	s	....	S
Pteris aquilina	....	s	....	S
Polystichum acrostichoides	O	s	a	S
Asplenium filix-femina	O	....	a	A
Aspidium marginale	....	....	a	A
Aspidium spinulosum, var. intermedium	....	....	a	A

TABLE IV.

Tests of Acidity With La Motte Indicators.

	No. tests.	300.	100.	30.	10.	3.	1.	3.	10.	Range.	Max.
Rock Ferns:											
Cheilanthes Feei	8	......	......	......	......	......	......	......	X̳	1	O
Asplenium parvulum	7	......	......	......	......	......	......	x	X̳	2	O
Pellaea atropurpurea	15	......	......	......	......	......	......	X	X̳	2	O
Woodsia obtusa	21	......	x	x	x	......	X̲	X̲	X	7	O
Cystopteris bulbifera	12	......	......	......	x	x	X̳	x	x	5	O
Cystopteris fragilis	15	......	......	x	x	X̳	X	x	X	6	S
Asplenium trichomanes	8	......	......	x	x	X̳	......	x	......	5	S
Polypodium polypodioides	10	x	x	x	x	X̳	x	......	......	6	S
Cheilanthes lanosa	11	......	x	x	x	X̳	......	......	......	4	S
Asplenium platyneuron	13	......	x	x	X̲	X	x	x	......	6	S
Camptosorus rhizophyllus	10	x	x	X̲	x	......	......	x	......	7	A
Polypodium vulgare	12	X	X̳	......	......	......	......	......	......	2	A
Asplenium pinnatifidum	5	X̳	x	......	......	......	......	......	......	2	A
Soil Ferns:											
Botrychium virginianum	16	......	x	......	......	X	X̲	x	x	7	O
Polystichum acrostichoides var. Schweinitzii	10	......	......	......	x	x	X̳	x	......	4	O
Osmunda cinnamomea	2	......	......	......	......	......	X̳	......	......	1	O
Adiantum pedatum	12	......	......	x	x	X	X̳	......	......	4	O
Polystichum acrostichoides	20	......	x	X	X	X̲	x	x	x	7	S
Phegopteris hexagonoptera	15	......	......	x	x	X̲	X	x	x	6	S
Asplenium acrostichoides	8	......	......	x	x	X̳	x	x	......	5	S
Asplenium angustifolium	9	......	......	......	X	X̳	x	......	......	3	S
Aspidium marginale	16	......	x	X	x	X̲	x	x	x	7	S
Aspidium spinulosum var. intermedium	10	......	......	x	X̳	x	x	......	......	4	S
Asplenium filix-femina	15	......	x	X̳	X	x	x	x	x	7	A
Pteris aqualina	6	......	......	X̳	x	......	......	......	......	2	A
Onoclea sensibilis	No data taken.										

TABLE V.

Wherry's Chart.

	Test.	300.	100.	30.	10.	3.	1.	3.	10.	30	Class.		Range.
Rock Ferns:													
Pellaea atropurpurea	30	......	......	x	X	X	X	X	X	X	C	S	O
Asplenium parvulum (resiliens)	15	......	......	......	......	x	X	X	X	X	C	S	O
Cystopteris bulbifera	30	......	......	x	X	X	X	X	X	x	C	N	O
Camptosorus rhizophyllus	50	......	......	x	X	X	X	X	X	X	C	S	O
Asplenium trichomanes	30	......	......	x	X	X	X	X	X	X	C	S	O
Woodsia obtusa	30	......	x	X	X	X	X	X	X	X	C	S	S
Cystopteris fragilis	30	......	x	X	X	X	X	X	X	x	C	N	S
Polypodium vulgare	50	......	x	X	X	X	X	X	X	x	C	N	S
Cheilanthes lanosa	15	......	x	X	X	x	x	......	......	......	A	S	A
Asplenium pinnatifidum	20	X	X	X	x	......	......	......	......	......	A	S	A
Asplenium platyneuron	50	X	X	X	X	X	X	X	X	x	I	S	A
Polypodium polypodioides	15	X	X	X	X	x	x	......	......	......	A	S	A
Soil Ferns:													
Adiantum pedatum	......	......	......	x	X	X	X	X	x	......	C	......	S
Asplenium angustifolium	10	......	......	x	X	X	X	X	x	......	C	......	S
Onoclea sensibilis	30	x	X	X	X	X	X	X	x	......	I	......	S
Polystichum acrostichoides	30	x	X	X	X	X	X	X	x	......	I	......	S
Asplenium acrostichoides	10	......	x	X	X	X	X	X	x	......	I	......	S
Phegopteris hexagonoptera	30	......	x	X	X	X	X	X	x	x	I	......	S
Aspidium marginale	30	......	x	X	X	X	X	X	x	x	I	......	S
Pteridium latiusculum (Pteris aquilina)	30	x	X	X	X	x	......	......	......	......	A	......	A
Aspidium spinulosum, var. intermedium	20	X	X	X	X	X	X	X	x	......	I	......	A
Osmunda cinnamomea	30	X	X	X	x	x	......	......	......	......	A	......	A

C—calcareous.
I—Indifferent.
A—acid.

N—North.
S—South.

O—neutral or alkaline.
S—slightly acid.
A—distinctly acid.

If we group these in the same way they were grouped in making the Grindley tests, we find that the results are practically the same. Wherry's tests are also included for comparison.

	Neutral-alkaline.		Slightly acid.		Decidedly acid.	
	Rock.	Soil.	Rock.	Soil.	Rock.	Soil.
Grindley	5	5	4	5	4	3
La Motte	5	4	5	6	3	2
Wherry	5	0	3	7	4	3

In copying Wherry's lists only the data is copied for ferns corresponding to species found in the Illinois Ozarks. The striking thing about this first comparison is that he found none of these soil ferns either decidedly alkaline or neutral, but 70% of them were slightly acid, the remaining 30% decidedly so. The soils he tested however ran as far as 30+ specific alkalinity, while those of the Ozarks did not run above 10+. Specific acidities of soil ran about the same. General soil tests in Southern Illinois showed that the rock soils ran to greater extremes in both alkalinity and acidity than the forest humus; consequently, we should expect the rock ferns through competition and natural dissemination of spores to reach greater extremes of life than that reached by soil forms. According to the same law we should expect the Eastern ferns to reach greater extremes of alkalinity; and so they did, one reaching 3+ specific alkalinity, but these were forms not native to the Illinois Ozarks, and consequently do not show in the chart.

By comparing the regional chart, Table I, with Table IV, the following points in regard to the rock forms are of interest.

1. There are three species found only on limestone, and these grow in decidedly subalkaline media.

2. There are four species found almost exclusively on the sandstone. These grow in soils either acid, subacid or mediacid.

3. For the rest of the rock forms and for all the soil ferns there seems to be no definite acidity habitat.

Some of the results may be deceptive, as in the case of the fern Osmunda cinnamomea, which here tests specifically neutral. It is but a single individual in the region, starting life in a limestone ravine. Its rhizome shows that it has been there for years. It apparently thrives without reproducing. It grows abundantly in our northern woods and swamps in soil that tests 30 to 300. It is given by Wherry with a maximum of 300. (3)

There seems nothing to prove that this striking contrast on the part of the rock ferns is due directly, or indirectly to soil acidity: in fact there are some evidences to the contrary.

The species showing these contrasts are all evergreen species, with a morphological and physiological xerophytism found in few plants of the cold temperate zone. In general the xerophytic characteristics of the calcicoles are:

1. A coriaceous evergreen foliage that can be neither baked in the sun nor frozen by the cold.

2. Rhizomes projecting into the crevices between the rocks to such depths that it is with the greatest difficulty that they can be extracted, and specimens are seldom secured whole.

3. Intolerant of shade, they each have individual light and heat relations to the sun which reduce temperature, light and transpiration. The following are illustrative details:

Cheilanthes Feei grows on the face of the vertical cliff in rosette form. The vertical rays strike but its edge, the south or western rays strike it only when they have spent their might. It has been found only on southern and western fronts of the Devonian limestone. Its pinnules are little pubescent hemispheres, cupping toward the surface of the rock, thus reducing the surface exposure to sunlight and transpiration. The pinnules are tiny and so scattered that when the fronds make a rosette, it takes dozens of fronds to catch the light creeping through the spaces between the pinnae. Even when growing they are so dry and brittle that one seldom secures perfect specimens. In this way the necessary moisture is reduced to a minimum.

Pellaea atropurpurea has one or two fronds with much larger pinnae. These fronds stand out from the rock in such a position as to present the frond's edge to the sun. Since the pinnae lie in one plane, Pellaea thus accomplishes what Cheilanthes Feei requires three devices to attain. Pellaea atropurpurea makes scarcely a shadow on the rock.

The fronds of Asplenium parvulum stand rigidly up from the rock, with the pinnae placed in rows on each side, aslant like the half open slats of a window shutter, with its edge directed toward the sun, and the light streaming through on the rock beneath. Thus it attains the same end as Cheilanthes and Pellaea.

A close second to these in xerophytic adaptation is the sandstone group. Their foliage is subcoriaceous and evergreen, being slightly affected by heat and cold, it holds within itself the power of recuperation.

Not having learned the advantage of hiding their rhizomes in the clefts of the rock, nor of turning the frond's edge to the direct ray of the sun; they resort to forming a mat on the rock face with the rhizomes, catching the soil, while the leaf mats form a thick protective mat above them. This is true of the two Polypodiums and of Camptosorus rhizophyllus. It is only partially true of Cheilanthes lanosa. Asplenium pinnatifidum has however the adaptive characteristics of the preceding group.

Besides the above, each has its individual way of meeting the drought exigency. To illustrate:

Cheilanthes lanosa dwells in pockets on the sunny edge of the cliff. Its pinnules are pubescent and circular. When it can no longer protect the soil beneath from the excessive drought, it resorts to the Feei method of curling its pinnules into half balls. It would then be difficult to distinguish from Feei except for its more erect position and larger size.

Asplenium pinnatifidum, Camptosorus and the polypodiums decorate the shaded face of the rock, thus securing but the slant sun-rays. In time of drought the Polypodiums have the power of folding their pinnae of the opposite sides together, then curling the frond from the tip toward the stipe, into a ball, and so awaiting the next shower. This power is so strong in the P. polypodioides that it has been given the name of 'Resurrection Fern'. Its exaggerated use of this power usually places it ten to fifty feet higher on the cliff than P. vulgare.

Camptosorus rhizophyllus is more mesophytic and hence more shade tolerant. It requires more soil for a foundation into which its rhizomes sink, and it forms with its fronds dense mats above them. The habit of regeneration at the tip of the frond makes the mats denser. If the fronds are dried up in time of dought, they simply break their connection with the younger plant, and each comes forth as a new individual when the moisture returns.

Asplenium platyneuron is shade tolerant. This entire sandstone group take advantage of underside transpiration of fronds to keep the soil and rhizomes from desication. Its expertness in this places the fronds so near the ground that transpiration forms a short circuit between soil and frond, keeping both moist in the average drought. The fruiting fronds stand erect, but complete their function in early summer. Their protection is a slight imitation of the window shutter method.

In gathering and drying specimens from the two different groups, it is easy to see that the sandstone ferns are noticeably richer in moisture content than the calcicoles, that likewise is the soil at their roots.

In such a gradation of xerophytic devices, one is inclined to emphasize the importance of this relationship, especially when he remembers that xerophytic structures are as necessary for bog as for dune life. So it is with the xerophytic, or rock ferns; they are acid and alkali resistant, or enduring, and not acid and basic loving.

Wherry's acidity tests show that these contrasts do exist; so do these studies in Southern Illinois, but the contrasts differ. For example: Polypodium polypodioides, a southern fern, in Wherry's tests ran into maximum specific acidity 300; Polypodium vulgare found its maximum at 10. In Southern Illinois tests P. polypodioides had its maximum at specific acidity 3, although it showed itself capable of living in higher acidities; P. vulgare had its maximum at 100 and did not run lower anywhere. What is the factor that reverses these fern habitats between Virginia and Southern Illinois. As has been shown, the striking difference between the Virginia and the Southern Illinois climate is the intense heat of summer. Since P. polypodioides is better adapted by its structure to endure these conditions, it runs ten to fifty feet higher on the sandstone, where there is little soil but its own frond mold. As a consequence its soil tests run the gamut of acidities from one to 300, only with the difference that here its maximum runs at acidity three. P. vulgare, on the contrary, less xerophytic in structure, adheres to the lower rocks where there is more soil, even when this soil be weathered to acidity 100.

Asplenium platyneuron ran to maximum specific acidity 300 in the Virginia tests, yet showed ability to live in soil 10 subalkaline. Is it strange that in Southern Illinois it seeks the deeper soil and an acidity of 10 when we consider its semi-xerophytic structure in a temperature of 100° F.?

Camptosorus rhizophyllus in a cooler climate grows on calcareous rock, and there finds the right amount of moisture when specific acidity is one, but in Southern Illinois that it may get sufficient moisture it must resort to sandstone with maximum 30.

The distinguishing factor between North and South, as far as the plant is concerned, is not the presence or absence of calcareous rock, as has been suggested. These are abundant in both regions. Temperature has changed and this factor affects the amount of soil water, and the amount of transpiration. This factor then has driven the semi-xerophytic forms from the dry limestone to a medium where more moisture is available.

Cystopteris bulbifera is another example of a fern growing on calcareous rocks in Virginia and found only on siliceous soils in the area under consideration. Gray says, "Chiefly calcareous rocks". Wherry found it in soil acidity one. Not being provided with xerophytic structures, its maximum is the same in Southern Illinois, but it betakes itself to deep siliceous soil and could in no way be considered a rock fern.

One thing quite noticeable in Wherry's chart when compared with the chart of the region under consideration is that while the Virginia ferns run into lower alkalinities the maximum is more acid than in Illinois. To express this in another way, the acidity range is much greater in Virginia than in Illinois. That is exactly what one would expect when temperature is lower and transpiration less.

In these very acid soils of Southern Illinois, why are the acid loving Osmundas not found, or rather why are they found but once; and found then on neutral soil? The answer must lie in some other factor than that of soil acidity.

Since soil acidity is scarcely met with in arid regions, one expects these semi-xerophytic forms to act just as they have in this case; to betake themselves to the sandstones in the low latitudes and to the limestones in the higher latitudes, and to do this not because of soil acidity, but to accommodate themselves to the proper amount of moisture.

GENERAL REMARKS.

The chart copied from Wherry was taken from the Smithsonian Report, 1920. The entire list was not copied, but only data connected with the ferns found in the region studied.

It is noticeable that Virginia soil ferns all ran much higher specific acidities than the ones studied in Illinois.

Dr. Wherry made many more tests for the majority of his ferns than were made for this study.

It is evident that much more data is needed on other areas before very definite conclusions can be drawn.

Some tests of the waterholding power of soils would not be out of place in this connection.

CONCLUSIONS.

In the same region different species of ferns vary much in soil habitat. Some grow in acid, others in neutral soils, while others grow indifferently in either.

The same species vary much in different sections.

Ferns growing directly on the rock are more variant in this respect than the soil ferns.

Some rock ferns grow always on the same kind of medium.

All exclusvely rock forms, except the most xerophytc, seem unable to dwell on limestone in a climate similar to Southern Illinois.

Both rock and soil forms seem capable of varying more in the higher than in the lower latitudes.

There seems to be no evidence that ferns betake themselves to either habitat in order to secure or to avoid acid or alkali.

There is much evidence in the varying xerophytic structures that it is the moisture of the habitat that controls the range of ferns on sandstone or limestone.

Rock ferns are more subject to extremes of drought, better equipped with xerophytic structures, and vary more in nature of habitat. Soil ferns are less subject to drought, are unprovided with xerophytic structures, consequently vary little in nature of habitat.

Calcareous rock in a Southern Illinois climate is a much drier habitat for plants than the same rock in a higher latitude.

In the region under consideration sandstone soil is a better medium for rank fern growth than the limestone, more because of the amount of soil water controlled by it than on account of the acidity or alkalinity of soil.

The distinction between calcicoles and silicicoles is more a question of moisture relation than of soil acidity.

LITERATURE CITED.

1. Clute, Willard N. Our Ferns in Their Haunts.
2. Gray, Asa. New Manual of Botany, Seventh Edition, 1908.
3. Wherry, E. T. Soil Acidity; Its Measurement, and Relation to Plant Distribution, Smithsonian Report, 247-268, 1920.
4. Colyer, F. H. Geography of the Ozarks, Trans. Ill. St. Acad. Sci. XIV, 36-43, 1921.
5. Weller, Stuart. Geology of Southern Illinois, Trans. Ill. St. Acad. Sci. XIV, 21-35, 1921.
6. Worthen, A. H. Geol. Sur. Ill., Vol. I, 77-152.
7. Worthen, A. H. Geol. Sur. Ill., Vol. I, 376-409, 1866.
8. Worthen, A. H. Geol. Sur. Ill., Vol. III, 58-83, 1868.
9. Worthen, A. H. Geol. Sur. Ill., Vol. III, 33-47, 1868.
10. Hill, E. J. Ferns of Illinois, Fern Bulletin, V. 20, 1912.
11. Amer. Fern Journal, 7-11, 1917-1921.
12. Lyell, K. M. Handbook of Ferns, 1870.
13. Parsons, F. T. How to Know the Ferns.
14. Wherry, E. T. Soil Acidity, Ecology I, 160-173, 1920.
15. Bessey, C. E. Maidenhair Fern, Bot. Gaz. 26, 211, 1898.
16. Meeham, Thos. The Native Flowers and Ferns of U. S.
17. Campbell, Douglas H. Mosses and Ferns, 1918.
18. Russell, Edward J. Soil Conditions and Plant Growth, 109-147, 1922.
19. Lyon and Buckman. Nature and Properties of Soil, Chap. XVIII. 345-383, 1922.
20. Bartholomew, J. G. Atlas of Meteorology, III, 1899.