OKLAHOMA GEOLOGICAL SURVEY

Carl C. Branson, Director

Circular 36

SPORES OF McALESTER COAL

By

James Leland Morgan

Norman, Oklahoma

1955

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FIGURES

MAPS

TABLES

PLATES

SPORES OF McALESTER-STIGLER COAL

BY

JAMES L. MORGAN

INTRODUCTION

Correlation by use of fossil spores and pollen has for many years been carried on with success in France, England, Germany, and other parts of Europe, utilizing a method of spore counting. The method is comparatively new in the United States, although much detailed and convincing stratigraphic work using spores as index fossils is now being done in this country.

This study is an attempt to utilize the spore-count method to correlate certain coal beds in the McAlester basin with coals of the shelf area.

The term "spore" may be defined as a reproductive body, typically unicellular, produced by plants and by some protozoans. It should be noted that the terms "spore" and "pollen" are not homologous—the microspore is the immediate product of division of the mother cell, whereas the pollen grain contains within its wall the microgametophyte developed from the microspore. However, since pollen analysis commonly deals also with spores, and since the methods used are closely related, it seems unnecessary to make use of a separate term, "spore analysis". Indeed, Florin (1937, pp. 328-329) makes no distinction between pollen grains and microspores:

> . . . the microspores of *Crossotheca* seem to differ from those of *Telangium*, however, by their lack of a distal germinal furrow of any kind. A prominent feature of the *Crossotheca* spores is the supposed peripheral cell-layer with well-defined walls sometimes visible even in carbonized material. The spores of *Telangium* do not exhibit this structure in the carbonized state of preservation, but in calcified material they show a reticulum which in all probability corresponds to the peripheral cell-layer in *Crossotheca*. This difference in the appearance of the pollen-grains of these two types of microsporangiate fructifications therefore seems to be rather quantitative than qualitative. In the size and shape of the spores the differences are inconsiderable . . .

Erdtman (1952, p. 11) states, "Cormophyte spores (here and subsequently 'spores' means pollen grains or spores or both, according to the context) are usually produced in fours (tetrads) by spore mother cells . . ." and Jackson (1949, pp. 234, 294) states in his definition of "microspore" that in recent years there is a tendency to use the terms "microspore" and "pollen" as synonyms.

All vascular plants produce spores of one type or another. Plants such as the ferns and related forms yield spores of the homosporous type. These are the male microspores and they range in size from about 10 to 100 microns, with the average size ranging from about 30 to 80 microns in diameter or greatest length. Another group of plants produces spores of two sizes. These are the heterosporous plants, which bear both the larger female megaspores and the smaller male microspores. Megaspores range in size from about 150 to several hundred microns. Stutzer and Noé (1940, p. 75) cite Lange as having fixed the boundary between megaspores and microspores at 0.1 mm or 100 microns in diameter and Wilson (1946, p. 111) states that microspores, because of their smaller size, are carried greater distances and are more evenly distributed over the region by air currents than would be possible for megaspores. Hence, they should be considered of greater value for correlation purposes than megaspores. However, authors of other papers disagree with this. Bailey (1935, p. 497 wrote: "The two types of spores are not distinguishable entirely on the basis of size, but also on their mode of development and function in the living plant." And Schopf, Wilson, and Bentall (1944, footnote 2, p. 9) state:

> The common indiscriminate reference to all spores of relatively small dimensions as ''microspores'' is to be lamented. Although true microspores frequently are small, by no means all small spores are microspores. The long established botanical usage of the term ''microspore'' has reference to fundamentally functional distinctions that are entirely aside from relative or specific size. R. B. Thompson (1927) has in fact demonstrated that in some plants the microspore is *larger* than the actual megaspore.

Raistrick (1934, pp. 14-22) gives the theory of correlation by spores in two fundamental assumptions: (1) that the spores were distributed from the parent plants by air currents, so that at any one particular time in the swamp where the coal was being formed, the innumerable spores produced would be mixed and wafted about in the wind so that a fairly uniform scatter was obtained, such that at any locality a statistical average of all types of spores would be found; and (2) that there would be enough difference in components of the flora of successive coal-seam swamps to give differences in percentage make-up. These assumptions were based on long experience of the use of tree pollen as a means of correlating existing peats.

The work of Kidston and other paleobotanists has indicated that the flora over a coal field was fairly uniform at any one time, and varied somewhat during the course of time. In other words, certain seams should show a characterization over the whole area by a particular flora, while a gradual change of flora will mark the vertical succession of coal seams (Raistrick and Simpson, 1933, pp. 230-231.)

Cain (1939, pp. 628-629) gives the following assumptions forming the basis of pollen analysis:

> 1) The structural characteristics of pollen grains are constant for a species. It does not follow, however, that the species of a genus can always be distinguished from each other.
>
> 2) Most dominant trees of the temperate zone have anemophilous pollen. This results in an average regional pollen rain which contains a mixture of the grains of the available species.
>
> 3) Many of the grains of the pollen rains which fall onto a bog surface, or which settle through the water to the bottom of a pond, are preserved under the antiseptic, low-oxidation conditions.
>
> 4) Year after year, as the peat or sediments accumulate, stratified pollen deposits occur.
>
> 5) Proper methods of sampling and preparation of the peat allow the detection, identification, and counting of the fossil pollen grains, which usually occur in abundance.
>
> 6) Consistent general trends in the pollen spectra from the samples of a boring, based on percentage composition of component pollen grain types, are a fact in most records. As a result, stratigraphic-time-vegetation-climate correlations can be made.

At least three factors of biological backgound aid in the correlation of strata by fossil spores and pollen: (1) the evolution of floras, (2) the migration and geographic distribution of floras, and (3) the influence of soil conditions on the plants. The floras of the world have evolved through geologic time, resulting in marked changes in form and structure. These changes are reflected in the morphology of the fossil spores and pollen, which are in many cases very different from one geological period to the next. Topographic and climatic changes have occurred within geological periods and these changes sometimes caused the complete elimination or mass migration of floras. In some instances the changes were cyclic and permitted the return of many species of plants that were previously forced to migrate. Marked changes in species of fossil spores and pollen result from mass shifting of floras in a region, making differentiation of the strata possible. Local environmental conditions cause ecological changes or restrict the number of species in a flora and serve to limit the fossil content of a stratum. Stratigraphic studies are aided by an understanding of these problems (Wilson, 1946, pp. 111-112).

Two conditions must be fulfilled if the microspore content of coals is to be used for correlation purposes: (1) the coal of different seams must differ sufficiently in proportion of spore types in the microspore content, or must include some type so expressive that the seams are readily distinguishable from each other and (2) the characteristics of each seam of coal must be sufficiently constant over a wide area (comparable to the area of the coal field) so as to be recognizable (Raistrick, 1935, p. 912).

Spores and pollen meet the requirements for correlation work and, at least in a limited capacity, have proved their worth. Most species of spores have an exine, or outer wall, impregnated with a wax-like fatty substance which renders them surprisingly resistant to decay, as well as to most acids (even concentrated sulphuric acid). They are also highly resistant to heat.

Spores are small and are easily disseminated over wide areas by air currents. Many species are widely and uniformly spread throughout a region and may be preserved in sediments such as coal (especially bituminous coal), many types of shale, some varieties of limestone, and in rare instances in sandstones.

Erdtman (1943, p. 1), in his book, *An Introduction to Pollen Analysis,* states:

> . . . Greenland peats contain pollen grains of pine and spruce, that must have been carried at least 100 kilometers (the distance of the nearest coniferous forest in Labrador). CHARLES LINDBERGH trapped pollen grains and spores by means of ''sky-hooks'' during a flight over Greenland. In 1937, the author collected pollen grains and spores by means of vacuum cleaners practically the whole way across the Atlantic between Gothenburg and New York. Among the pollen grains thus obtained American specimens were found at least as far as 700 kilometers east of Newfoundland . . . .

Results have been attained with fossil spores and pollen which show conclusively that practically all coals and shales thus far studied can be assigned within the limits of geological periods, and that various strata can be separated from one another by the specific abundance of various species of fossil spores and pollen, or spore and pollen facies (Wilson, 1946, p. 120). Luber (1937, p. 61) found that over 500 spore analyses for 22 beds of the Karaganda and Kizel basins showed every bed to be characterized by a definite combination of spore species in relatively constant quantitative proportions which persisted over a considerable distance and were not repeated in other seams.

In 1941 Godwin (p. 329), in his paper on pollen analysis, wrote:

> . . . So far as north-western Europe is concerned, it is already true that pollen-analysis has thus yielded a background scale against which can be seen all types of geological change. Quite apart from the intrinsic evidence afforded by the knowledge of the former extent of specific trees of which we know the present climatic range, the parallel drift of pollen curves over a wide area would still afford, even if the grains could not be identified, a valuable means of correlation. This is especially so since the grains are so widespread, and conditions suitable for preservation so abundant, that there are immense areas very rich in material capable of pollen analytic treatment.
>
> It should be noted that although so much pollen analytic work has been restricted to the post-glacial period,

> there is no inherent reason why it should not be applied with equal success to inter-glacial or even older formations. Indeed in Denmark and Poland particularly, long sequences of forest history through different inter-glacial periods have already been established by this means. . . .

Since a knowledge of the fossil flora or fauna of the different geological periods provides a basis for determining the relative position of geologic strata, it would seem that studies of fossil spores and pollen also have a fundamental importance in the same field.

One of the important reasons for different types of coal is variation in the original plant constituents. Spores offer an unusual opportunity for obtaining definite information of the plant communities which contributed to the various coal beds.

Scope and Purpose of Report

There are many coal occurrences in Oklahoma which have not been certainly correlated with named coals. The Stigler coal of the McAlester basin has not been identified in northeastern Oklahoma, but there are several coals of the approximate stratigraphic level, one of which may be shown to be the correlative. The Upper Hartshorne coal may correlate with the Riverton coal. It is believed that a careful study and count of spore types will show whether these coal beds have been properly correlated.

Work of this kind has never been done in this area and correlations are needed to tie coal beds of the McAlester basin to those in the platform area. The outcrops of these beds have never been accurately traced out by surface mapping—it has been impossible to do so because the Warner uplift and the Arkansas River alluvium effectively break the continuity of outcrop of the coal beds. Correlation of these coal beds would be of extreme importance in the stratigraphy of this area.

History

Wilson (1946, p. 112), Thiessen (1920, p. 3), and Kosanke (1950, pp. 7-8) credit Henry T. M. Witham with being probably the first to observe fossil plant spores. Witham (1833, p. 50) noticed and illustrated "decided traces of organization" in thin sections of cannel coal from Lancashire, England. He was inclined to believe they were monocotyledonous plant remains, but the studies of James Bennie and Robert Kidston in 1886 revealed that Witham's "traces of organization" showed many megaspores and not monocotyledonous vessels, with certain indications which suggested the presence also of microspores in Witham's thin coal sections.

Wodehouse (1935a, pp. 17-18) dates the origin of the microscopic study of Recent pollen grains over 160 years earlier in crediting Nehemiah Grew of England and Marcello Malpighi of Italy with being the first to observe and describe pollen grains. Both Grew and Malpighi, who did their studies almost simultaneously, were quite familiar with the other's work and borrowed freely from each other (with as complete acknowledgment as was customary at that time). The first of Grew's essays, "The Anatomy of Vegetables Begun", was published in 1671 by the Royal Society of London. In the same year Malpighi submitted to the Royal Society his paper, "Idea", in manuscript form.

Erdtman (1943, p. 3) names Lennart von Post as being the founder of modern pollen analysis with the latter's paper in 1916 on fossil pollen of Swedish bogs. Erdtman points out, however, that he does not imply that pollen analysis is the product of spontaneous creation, but rather, that it had ". . . a long line of forebears, of parents and grandparents, a period of gestation, when it was unknown except among a few hopeful workers."

In 1855 Franz Schulze made one of the most important contributions to the study of isolated plant remains in coal with his discovery that coal could be macerated with a solution of potassium chlorate and concentrated nitric acid without damage to the botanical constituents. Thus, with the thin sections of Witham and the maceration method of Schulze, two methods by which the botanical contents of coal can be studied microscopically have been known for approximately 100 years. These methods with minor improvements are still in use.

Knox (1952, p. 333) names Raistrick and Simpson as being the first to present a systematic account of the method of microspore analysis and the first to indicate its possibilities for the correlation of coal seams in England with their paper in 1933 on the "Microspores of Some Northumberland Coal Seams".

Since 1933 numerous papers have appeared dealing with spores from Paleozoic coal deposits, yet as recently as 1947 Kosanke (p. 280) wrote that the use of spores in solving straigraphic problems was practically unknown in this country.

ACKNOWLEDGMENTS

The writer wishes to express sincere gratitude to Dr. Carl C. Branson, Professor of Geology and Director of the Oklahoma Geological Survey, for suggesting this problem and for his generous assistance and constructive criticism, both in the field and during the preparation of this report. Grateful acknowledgment is also made to Dr. William S. Hoffmeister of Carter Oil Company's Research Laboratory in Tulsa, Oklahoma, for technical guidance and assistance in conjunction with the laboratory techniques used in preparing the coal samples; to Dr. Kaspar Arbenz, Associate Professor of Geology, for making available space and equipment in the sedimentation laboratory; to Mrs. Inez K. Jeffs, librarian of the Biology Library, for her generous aid in locating relevant botanical information; to Mrs. Lucy H. Finnerty, librarian of the Geology Library, for her assistance in obtaining certain geological references; to Berton J. Scull, graduate student at the University of Oklahoma, for various helpful suggestions in the writing of this paper; and last, but not least, to my wife, Blanche, for patiently encouraging me.

EQUIPMENT

Field Equipment

The equipment needed for collecting samples is simple and the number of items few. An all-steel "wood-chisel" with a blade about one inch wide was used in cutting channel samples completely through the coal seams from top to bottom. This chisel is made in one piece, having a steel shank which will withstand heavy hammering without breaking as compared to the average wood-chisel which has either a plastic or wooden handle. A small machinists' hammer of about eight ounces to one pound in weight is ideal for use in driving the chisel through the coal. Other items needed are a small steel tape or folding carpenters' rule for measuring the thickness of the seams, paper or canvas bags for carrying and keeping the samples separate, and shipping tags or other means of identifying the individual bags of samples. A small spade is useful in clearing away part of the overburden of many of the coal seams from which samples are desired, and is an excellent means of catching the fragments of coal as they are chipped from the face of a coal seam.

Laboratory Equipment

In contrast to the equipment needed for the field work, that need for the laboratory work is more complex and the items more numerous. A slide ringer patterned after one used by Carter Oil Company's Research Laboratory in Tulsa, Oklahoma, was constructed. In using the slide ringer, a microslide is placed under the clamps on the turntable of the slide ringer so that the cover glass is centered with respect to the guide rings, a number 00 sable brush is dipped in asphaltum varnish thinned with carbon tetrachloride, the turntable given a spin, and with the hand resting on the handrest, the tip of the brush is held against the edge of the cover glass where it meets the microslide. Thus a seal of the rapid-drying asphaltum varnish is formed completely around the cover glass to help prevent deterioration of the mounting medium. With a little experimentation on the consistency of the varnish and a bit of practice with the slide ringer, the ability to make professional-quality slides can quickly be attained.

A rack (copied from one used by Carter Oil Company's Research Laboratory, Tulsa, Oklahoma) was used to hold the freshly made microslides in an upside down position until the glycerine jelly becomes set, thus allowing the spores to settle toward the cover glass. The rack is also useful in holding the freshly ringed slides until the asphaltum varnish dries.

A desiccator with calcium chloride drying agent is used in removing moisture from the glycerine jelly medium containing the spores. Other items of laboratory equipment should include a ventilating hood, small electric hotplate, centrifuge, plastic centrifuge tubes, copper beakers, plastic face shield, rubber gloves and apron, microscope, and a steel mortar and pestle.

The microscope (such as the Leitz "Ortholux") should have a calibrated mechanical stage and be capable of giving magnifications of at least 180 diameters. Wilson (1946, p. 115) recommends a compound binocular microscope equipped with oculars of 5, 10, and 15 power and objectives of 10 mm, 3 mm, and an oil immersion lens. Various combinations of these same lenses may also be used for making photographic records. Since most spore studies are carried on in transmitted light, substage illumination should be provided. An ocular measuring disc mounted in one of the oculars and calibrated with a stage micrometer is ideal for making necessary measurements. The disc may be kept permanently in one of the oculars or mounted in a duplicate ocular which may be removed when not in use.

Field Procedures

The method of sample collecting generally applied to coal is the practice of cutting a channel sample from the face or outcrop of the coal seam. This may consist of either cutting a uniform sample completely through a seam to make one sample, or of dividing the seam into two or more samples according to the number of shale or pyrite partings. For correlation purposes the latter practice seems more desirable and was therefore used in this study.

The coal seam to be sampled is first cleaned on top by using a spade or other instrument to remove any overburden, and any remaining loose material is brushed off. If the face of the seam is not a fresh one, a hammer and sharp chisel are used to clean a section of the face to get rid of foreign matter and to determine if any partings are present. The exact bottom of the seam is then located, part of the underlying material removed at the place to be sampled, and the thickness of the seam measured. The point of the spade is then inserted below the coal seam to catch the falling pieces of coal and a channel sample is cut with the hammer and chisel from top to bottom of the seam, dividing the sample according to any partings which may be present. The samples are collected in a canvas bag, properly labeled with a tag, and the top of the bag tied securely with string or wire to prevent possible contamination. Although a few grams of coal are enough for macerating, it is desirable to collect at least a pound or two for each sample to give a better representation of the seam as a whole.

Raistrick (1934, p. 142) states that repeated experiments have indicated that a channel sample of a coal seam is sufficiently reliable for general correlation purposes, and that "So long as the methods of grinding, sampling, and treatment are kept strictly the same for all samples, the separations will have the same value for comparison . . ."

Laboratory Procedures

Certain components of coal can be made soluble by oxidation with acids and then removed by alkalies. Humic matter reacts particularly well to this treatment. Spores, cuticle, and other plant constituents that remain are bleached by the process, often making even the most delicate structure visible under the microscope.

Several methods have been employed in separating the spores from coals and peats. Since various samples present different problems in macerating, a number of methods for the preparation of both peat and coal will be given here in an attempt to cover as many as possible of the types of coal likely to be encountered.

The most commonly used reagent is Schulze's solution, which consists ordinarily of 3 parts of potassium chlorate and 20 parts of concentrated nitric acid (specific gravity 1.16), although the concentration varies with the character of the coal. Increasing the amount of potassium chlorate increases the strength of the mixture and the rate of oxidation. Brown coals require less oxidizing than bituminous and coals of higher rank, hence the mixture should be more dilute. The reagent should be prepared immediately before it is to be used. The reaction may require several hours to several weeks, at the end of which time the preparation may be treated as follows (Stutzer and Noé, 1940, p. 59):

> . . . After successful bleaching, the preparation is washed with 70-80 percent alcohol and then with ammonia. The liquid is best removed with a pipette, after which the residues are ready for microscopic attention.
>
> Diaphanol should be used in case of coals with low carbon content. After a short application the remains consist of cellulose, cutin, and suberin, the woody tissues having been dissolved. A preparation which is called "Diaphane Rapid," a solution of chlorine dioxide in monochloroacetic acid, acts faster. It is not necessary to treat afterward with ammonia or alkali.
>
> Other means of oxidation may also be used. Eau de Javelle (sodium hypochlorite) and Hoffmeister's reagent ($HCl + KClO_3$) are recommended. Not one but several reagents should be applied to some coals. The different kinds of coal are affected differently by the acids. Principally bituminous bodies, like spores, pollen grains, and cuticles, are left after maceration.
>
> The residues which are left after maceration can be stained, preferably red, in order to emphasize the plant structures. This is especially desirable if photomicrographic reproduction is contemplated. The residues are dehydrated in alcohol and imbedded in Canada balsam.

In addition to Schulze's solution and Diaphanol (an acetic acid and water solution of chlorine dioxide), other oxidizing agents which may be employed are: chromic acid (a solution of potassium dichromate, sulphuric acid, and water); fuming nitric acid; aqua regia; a mixture of 2 parts hydrofluoric acid, 2 parts hydrochloric acid, and one part acetone; and a saturated solution of nitric acid and chromic hydroxide. Calcareous sediments are treated with hydrochloric acid, and siliceous materials require the use of hydrofluoric acid.

Wilson's excellent account of maceration methods in his paper on "The Correlation of Sedimentary Rocks by Fossil Spores and Pollen" in 1946 (p. 113), bears repeating in part as follows:

> . . . Some of the low rank coals can be prepared in the same manner as peat but usually it is necessary to use strong solutions of potassium hydroxide or ammonium hydroxide to prepare the coarsely pulverized coal. Whereas peat frequently disperses immediately it is sometimes necessary to allow the coal to remain in the digesting solution a number of hours. When the digesting process is completed it is necessary to dilute the solution with water and by a series of decantations or by centrifuging to obtain the residue which consists largely of spores, pollen, and vegetative plant parts.
>
> The work with higher ranks of coal, and some lower involves the use of stronger digesting solutions than is necessary with most brown coals. The most frequently used method is that with Schultze's solution for a period of twelve to eighteen hours. Several grams of finely broken coal are placed in a beaker and covered with Schultze's solution. Since the chemical reaction may be violent, it is desirable to carry on the process under a laboratory hood. In the course of the digesting process, the mixture should be stirred several times with a glass rod. If at the end of about twelve hours all apparent reaction has stopped, the mixture is washed with water and decanted. Usually it is necessary to decant the material several times. After the last washing the coal sediment is covered with ammonium hydroxide and allowed to remain another twelve to twenty-four hours. It, too, should be stirred several times in the course of the process. At the end of the ammonium hydroxide application, water is again added and decanted. After the second decantation, the liquid may be centrifuged and washed until there is no longer a detectable odor of ammonium hydroxide. Stain may be added to the sediment at this point and when the proper intensity is obtained, the material is washed until the water no longer is colored. Temporary water mounts may be made and used for study without further preparation.
>
> Frequently the above schedule will not apply to certain higher rank coals for some will macerate more or less easily than others. In some coals the fossils will be badly corroded, while in others the fossils will not be separated from the matrix, consequently it will be necessary to modify the time of Schutze's solution treatment. Therefore it is desirable to keep rather complete notes on the procedure used on each sample . . . .

Raistrick (1937, pp. 909-910) describes a modification of the Schultze's solution treatment which has been found during this study to be successful in the treatment of certain higher rank coals. The coal is first crushed to pass a 30 or 40 mesh sieve with a minimum amount of fine dust. A small amount of this crushed coal is then mixed dry with an equal weight of potassium chlorate, to which is added about ten times as much concentrated nitric acid. The mixture is permitted to stand for two days (with several shakings meanwhile), by which time the coal should be completely oxidized. The reddish-brown liquid is then carefully decanted and the residue washed free of acid. A ten percent solution of potassium hydroxide is then added to the settlings and again allowed to stand for two days, with occasional shakings. The black liquid present is then decanted and the residue washed until the water remains clear. This "dry" method is much more vigorous in reaction than the usual Schultze's solution on certain American coals and it is claimed by some writers that the results are not sufficiently better to warrant its use.

Raistrick (1934, p. 143) offers a suggestion for treatment before maceration of high rank coals from which difficulty has been experienced in obtaining separations:

> . . . the difficulty is lessened if the coal, before treatment with the Schulze solution, is soaked for a day in pyridine. This certainly loosens the texture and slightly swells the coal particles, and the subsequent treatment is facilitated. The pyridine is best washed out of the coal with dilute hydrochloric acid, followed by water, the acid converting the pyridine to a water-soluble compound.

G. and H. Erdtman (1933, pp. 354-356) have proposed a maceration method based on mild oxidation followed by acid hydrolysis, in which the oxidizing agent is sodium chlorate in a mixture of acetic and sulphuric acids.

Dr. Howard W. Larsh (personal communication, January, 1955) states that he has found cotton blue to be far superior as a stain for the lactophenol. To 20 grams phenol crystals, 20 mls. lactic acid, 40 mls. glycerine, and 20 mls. distilled water (mixed in a suitable container and melted under warm tap water) 0.05 grams of cotton blue are added.

The alkali method, like the preceding one, is used chiefly for the preparation of peat samples but may prove useful in treating weathered coal or coals of low rank. Usually a small amount of peat is placed on a microslide and mixed with a few drops of 10 percent potassium hydroxide. The slide is held with a clothes pin and the mixture is carefully boiled over a small alcohol lamp until most of the water is evaporated. The macerated material may then be examined directly by mixing with a few drops of glycerine, transferring a small amount to another slide, and covering with a cover glass, or it may first be washed with distilled water and then mounted in glycerine jelly, either unstained or colored with safranin.

Glycerine jelly may be purchased or may be prepared in the laboratory in the following way:

> Dissolve one ounce of unflavored gelatine in 6 ounces of distilled water. When the gelatine has dissolved, add 7 ounces of glycerine and 2 drams of carbolic acid. Warm the mixture for 15 minutes while stirring constantly, keeping the temperature below 75° Centigrade. Allow the mixture to cool and on solidification, drain off any surplus water that may remain. The jelly should be kept in an air-tight jar in a cool place.

The principal maceration method used in this study is a variation of the Schultze's solution method similar to Raistrick's "dry" method described earlier. This method, used by Carter Oil Company's Research Laboratory (Dr. William S. Hoffmeister, personal communication, January, 1953), is especially desirable where the saving of time is an important factor.

The large sample of coal (one to five pounds) is first broken into small pieces with a hammer and the entire sample well mixed. From this mix, about a double handful is removed to a mortar and crushed with the pestle until all the pieces have been reduced in size to less than about ¼ inch. Any pieces of coal that fall out are not returned to the mortar in order to avoid possible contamination. The contents of the mortar are then dumped onto a clean cardboard or heavy paper, and thoroughly mixed and quartered. One quarter of the sample is returned to the mortar, the remaining three quarters are replaced in the sample bag. The mortar and pestle are again used to break any pieces larger than desired which may have escaped notice in the first crushing operation. In so doing, most of the other pieces of coal in the mortar will be further reduced in size. The coal is then dumped onto the cardboard and the mixing and quartering operation performed again. This process is repeated until the one quarter of sample remaining has been reduced to the desired amount (about 10 grams) for macerating. The sample thus mixed and quartered is a good representative fraction of the coal seam from the locality where it was collected.

The quarter of coal to be macerated is then poured into a clean 1000 ml. beaker with no effort being made to screen the sample or to remove the fine dust. A roughly equal amount of dry potassium chlorate is added to the beaker and thoroughly mixed with a glass rod (caution should be exercised since a mixture of potassium chlorate and carbon is highly combustible and may be set off by grinding; this especially so if sulfur is present). The beaker is then placed in the laboratory hood and, with face and hands protected by plastic mask and rubber gloves, enough concentrated nitric acid added to cover the mixture. CAUTION: this operation can be exceedingly dangerous—the reaction sometimes proceeds so rapidly as to cause an explosion. Usually enough heat is generated by the reaction to cause the mixture to boil violently, and it has been found by experiments that a cover placed over the beaker to prevent contamination from possible explosion of another sample actually increases the danger of the covered mixture exploding by confining the heat generated, which in turn increases the rate of reaction. Occasionally a sample will not react at all with the acid, in which case it may be necessary to heat the mixture cautiously to start the reaction.

When all apparent reaction of the mixture has stopped, the contents of the beaker are well diluted with distilled water and stirred with a clean glass rod. A centrifuge tube is filled with a portion of the reddish-brown liquid and the mixture in the tube is centrifuged for about one minute and the dilute acid decanted. This is followed by several washings with distilled water and centrifuging until the pH of the contents is about 7.0. After the last decantation, a few cubic centimeters of 5 or 10 percent KOH or NH_4OH is poured over the sediment in the tube to deflocculate and disperse the humic matter. The liquid should turn black almost instantly if the oxidation of the coal is complete. A test should be made immediately, followed by other tests every few minutes, to determine if spores are being separated from the matrix and to avoid etching of the exine by too much reaction from the alkali.

Such a test may be made by placing a drop of glycerine on a clean slide, stirring in a bit of the mixture picked up from the centrifuge tube on the end of a clean glass rod, and covering with a cover glass. When abundant spores are found in the test, sufficient distilled water is added to fill the centrifuge tube, and the contents centrifuged, washed, and decanted until the water comes off clear. If it is so desired, the spores may be stained at this time by adding 10 or 12 drops of safranin to the sediment in the tube and shaking or stirring for a few seconds with about 50 mls. distilled water. The mixture is then centrifuged and as much of the water as possible poured off.

If the coal contains siliceous matter, the sediment (before staining) should be transferred to a copper beaker, covered with hydrofluoric acid, returned to the ventilating hood, and left for 8 to 14 hours. At the end of this time, the mixture is diluted with distilled water, placed in plastic centrifuge tubes, and centrifuged and washed until free of acid. It may be necessary with some coals to repeat the treatment with ammonium or potassium hydroxides at this point. In at least one instance, no spores at all were found in the tests until after this operation, at which time well-preserved spores appeared in abundance.

A few cubic centimeters of melted glycerine jelly are stirred with the sediments in the centrifuge tube after the last washing and draining and the resulting mixture poured into a small, wide-mouth, screw-top bottle which has been previously cleaned and labeled with the necessary data. The bottle is then placed uncovered in the desiccator and left for about 12 hours to remove moisture from the gelatin.

When the gelatin has been properly dehydrated, it is remelted by standing the bottle in a Petri dish containing water and heated on a small electric hotplate. A small glass stirring rod is used to stir the mixture and to transfer a drop of it to each of 5 or 10 properly labeled microslides. A round cover glass is then dropped carefully over each drop of the mixture on the slides. If the mixture is sufficiently warm, it should spread out evenly to the edges of the cover glasses. In some cases it will be necessary to hold the slide on the warm hotplate for a few seconds and/or to apply pressure lightly to the cover glass to obtain even distribution of the jelly. Care should be exercised not to apply too much pressure as this forces the smaller spores out from under the cover glass, causing an over-representation of the larger spores.

As each slide is completed, it is placed upside down in the slide rack to allow the spores to settle toward the cover glass while the glycerine jelly medium is in the process of setting. The slides should remain in the rack for approximately one hour, at which time they are ready for ringing with asphaltum varnish.

When the varnish is dry (about 5 minutes is sufficient time) the slides are ready for examination under the microscope.

Plant microfossils may be mounted in any of several media, the most frequently used of which are glycerine jelly and diaphane. The diaphane is advantageous in being somewhat more transparent than glycerine jelly, but the simplicity of the glycerine jelly method makes it possible to prepare a large number of slides in a short time. Canada balsam may be used, especially for mounting large individual specimens, but has the disadvantage of requiring about three weeks to dry, since it is impractical to heat it during the process of mounting, and its high index of refraction is a disadvantage in many studies. For temporary mounts, Karo syrup or water-glass may be used, but these media tend to become crystallized over a period of years. The glycerine jelly mounts, though fairly permanent, must not be subjected to warm temperatures for any great amount of time, and air bubbles tend to develop in the jelly mount if the sediments were not sufficiently washed following the oxidation process.

The number of spores that should be counted for sufficient accuracy in correlation work is not established and varies widely among different workers. Wilson (1946, p. 118) notes that the exploratory work in this country has usually been done with counts of 1000, but that satisfactory results have been obtained with counts of 500 where a dozen or more species were involved, and 200 where 6 or 8 dominant spores were counted. In the same paper (p. 119) Wilson states that experiments with seams of coal have indicated:

> . . . that the dominant fossils will frequently vary between 5 and 10 per cent in a 200 fossil count, if the samples are collected several miles apart, or the maceration process has not been uniform. In the first instance, areal distribution of the ancient vegetation apparently is a factor, or the coal seam was thicker or more completely represented at one locality than at another. In the second instance, where uniformity of maceration is not attained, fossils with various thicknesses of spore or pollen coat, or great differences in size, will appear in variable percentages.

Erdtman (1931, p. 400) has obtained trustworthy percentages with counts of 150. Raistrick used a count of several thousand in his early work with the Carboniferous coals in England. A count of 200 spores for each sample was used in the present study, a count recommended by Luber (1937, p. 61) " . . . The average proportion of the various species of spores in the sample studied may be established with sufficient precision by calculating 200 specimens . . . .", and by Barkley in his paper on "The Statistical Theory of Pollen Analysis" (1934, p. 288) in which he states that " . . . little or no validity accrues from counting above 200 pollen grains per slide . . . ." and (p. 287), ". . . a count of 175 to 200 grains should be considered sufficient."

In counting the spores, a slide is placed in position under the microscope, the right half of the slide holder is adjusted so that the index mark coincides with the 100 mark adjustment, and the slide thoroughly and methodically searched for spores with the aid of the mechanical stage. When it is desired to return to a certain specimen on the slide at a later date for the purpose of making a photograph or for re-inspection, the spore is centered in the field of view and the readings of the lateral or "horizontal" and the transverse or "vertical" calibrations noted on paper, along with the slide number, e.g., Slide No. C-36; H-125.4; V-110.7. With this method it is possible to return to any previously noted specimen rapidly without even the necessity for looking through the microscope during the procedure.

The first identifiable spores encountered (pieces of broken spores and unrecognizable specimens are disregarded) are counted by types from a minimum of two slides. The total number of each type is then converted to its respective percentage of 200 and the percentages plotted as a histogram or bar graph. Correlations (or noncorrelations) may then be determined by a comparison of the histograms of the various seams represented.

Locations of Coal Samples

Sample Ia: Top one foot of the McAlester coal from the Lone Star Steel Company's Carbon mine number 5, near Carbon, Oklahoma, approximately 1200 feet below the surface in a slope mine under the NW¼ sec. 5, T. 5 N., R. 16 E., Pittsburg County, Oklahoma, July 30, 1954. Sample collected from the fresh face of the 36-inch thick seam.

Sample Ib: Middle one foot of the same.

Sample Ic: Bottom one foot of the same.

Sample II: Random chunks of McAlester coal collected from spoil heap of an old strip pit, SE¼ sec. 36, T. 6 N., R. 15 E., Pittsburg County, Oklahoma, July 30, 1954.

Sample III. Top 16 inches of a 20-inch seam of Stigler coal in the SE¼ NE¼ sec. 17, T. 9 N., R. 20 E., east of Whitefield, Haskell County, Oklahoma, August 19, 1954.

Sample IVa: Top 13 inches of a 20-inch seam of Stigler coal from the Garland Mining Company strip pit in the SE¼ sec. 8, T. 9 N., R. 23 E., northeast of Keota, Haskell County, Oklahoma, August 19, 1954.

Sample IVb: Bottom 7 inches of the same.

Sample V: Upper Hartshorne (?) coal collected from a road-cut along U. S. Highway 64, in the NW¼ sec. 26, T. 11 N., R. 25 E., on Wildhorse Mountain, west and south of Muldrow, Sequoyah County, Oklahoma, August 19, 1954.

Sample VIa: Upper 10 inches of a 20-inch seam of Stigler coal in the NE corner sec. 4, T. 11 N., R. 24 E., east of Sallisaw, Sequoyah County, Oklahoma, August 19, 1954.

Sample VIb: Lower 10 inches of the same.

Sample VIIa: Upper one foot of a 24-inch seam of coal in the S¼ corner sec. 33, T. 12 N., R. 23 E., southeast of McKey, Sequoyah County, Oklahoma, August 19, 1954.

Sample VIIb: Lower one foot of the same coal.

Sample VIII: Stigler coal (estimated 13 inches thick) from the E¼ corner sec. 13, T. 13 N., R. 18 E., north of Keefeton, Muskogee County, Oklahoma, August 19, 1954.

Sample IX: Second coal beneath the Spaniard limestone, C. N½ sec. 2, T. 14 N., R. 18 E., south of Muskogee, Muskogee County, Oklahoma, August 19, 1954.

Sample X: Rowe coal from the SE¼ NW¼ sec. 33, T. 17 N., R. 18 E., Wagoner County, Oklahoma, August 19, 1954.

Sample XI: Rowe coal collected from the bank of a small stream next to a strip pit in the C. SE¼ sec. 6, T. 17 N., R. 18 E., north of Blue Mound, Wagoner County, Oklahoma, August 19, 1954.

Sample XII: Coal at the base of the Spaniard limestone, collected in a roadcut along State Highway 20 in the NW corner sec. 15, T. 21 N., R. 18 E., west of Pryor, Mayes County, Oklahoma, May 14, 1954.

Sample XIII: Coal eight feet below the Spaniard limestone. Same location.

Sample XIV: Upper coal bed of the Steppe Ford section in the W½ SE¼ sec. 5, T. 28 N., R. 22 E., west of Miami, Ottawa County, Oklahoma, May 14, 1954.

Sample XV: Riverton coal from an old sink hole in the C. NE¼ sec. 9, T. 32 S., R. 25 E., Cherokee County, Kansas, December 4, 1953.

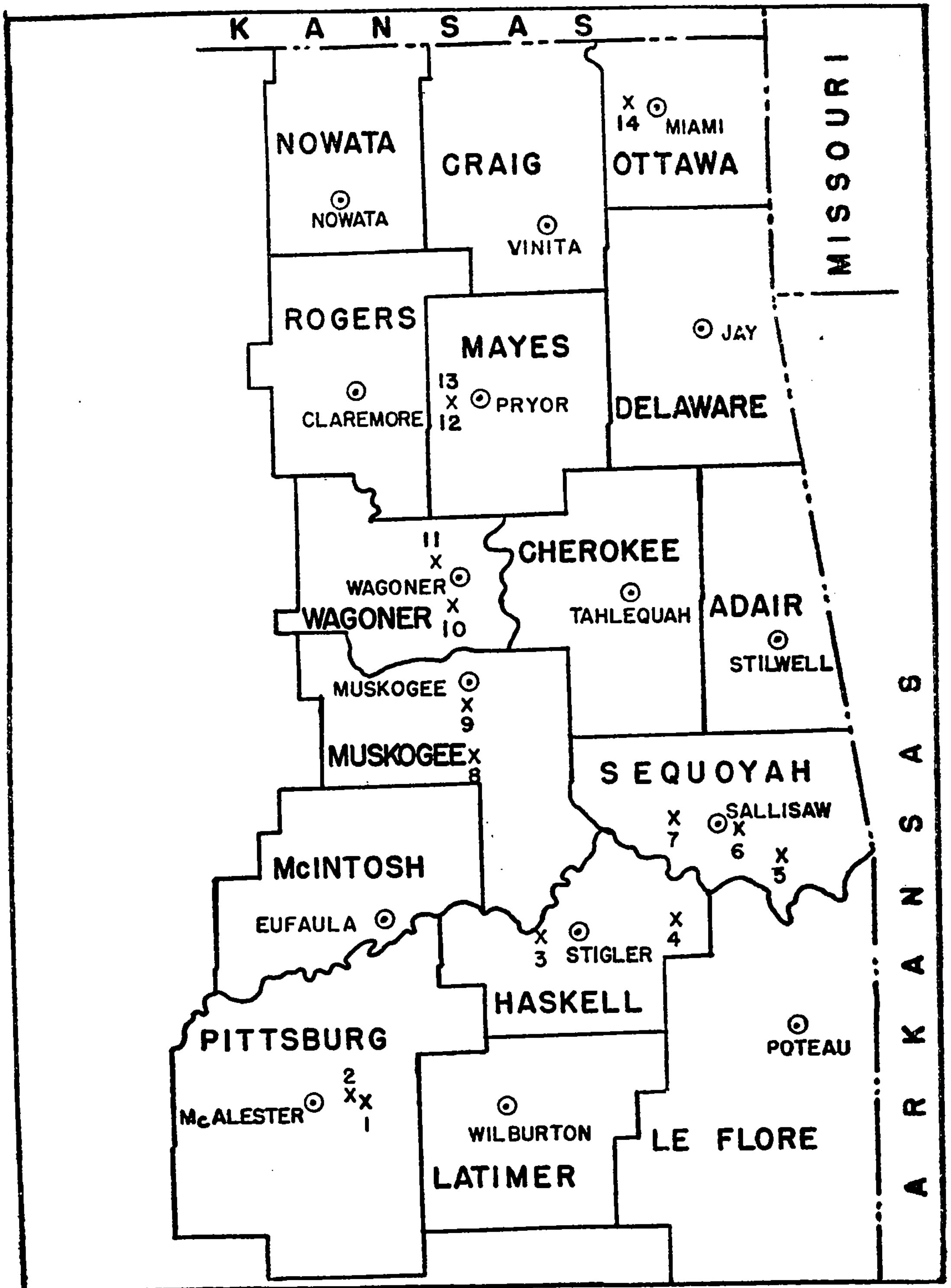
STRATIGRAPHY

Southeastern Kansas. In southeastern Kansas the basal unit of the Pennsylvanian strata is the Cherokee shale, which lies unconformably on limestone of Mississippian age. The Cherokee shale is made up of alternating beds of sandstone, limestone and shale. The Cherokee shale formation contains many marine fossil horizons and numerous coal beds indicative of recurrent marine and continental deposition. The lower half of the formation contains abundant black and dark gray shale while the upper part is commonly gray, well laminated shale with black shale above some of the coal beds. The Riverton coal, 6 to 14 inches thick, lies above the basal shale unit of the Cherokee formation. The Riverton coal is overlain at places by as much as 2 feet of black shale; at other places the coal is overlain directly by the Little Cabin sandstone; at still other places the Little Cabin cuts out the Riverton coal entirely with the exception of coal fragments which may at places be found in the basal part of the sandstone (Pierce and Courtier, 1937, pp. 19-23).

The McAlester Basin Platform Area. The lower part of the Des Moines series of the McAlester basin platform area is the Krebs group, consisting of the Hartshorne, McAlester, Savanna, and Boggy formations. Subdivisions of the Krebs group are listed below with the youngest at the top:

- Des Moines series
  - Krebs group
    - Boggy formation
      - Bluejacket sandstone member
    - Savanna formation
      - Unnamed shale member
      - Doneley limestone member
      - Unnamed member
      - Rowe coal
      - Unnamed member
    - McAlester formation
      - Unnamed member
      - Warner sandstone member
    - Hartshorne formation

Regarding the rocks, Branson (Reed, Schoff, and Branson, 1955, p. 63) states:



LOCATION MAP

All these rocks are deposits of the stable shelf which extends northward from the McAlester basin. They rest unconformably upon Fayetteville shale and limestone in the southwestern part of the county, upon the Hindsville limestone near Miami, and upon the Boone formation in adjacent parts of Kansas. The rocks of Springer, Morrow, and Atoka age are overlapped southwest of Ottawa County.

The Hartshorne formation of the northern platform area consists of the following subdivisions (Branson, 1954, p. 6):

Hartshorne formation

Riverton coal
Underclay, shale
"Elm Creek" limestone
Shale
Siltstone
Coal
Underclay, shale
Sandstone, conglomerate

The basal conglomerate, which is composed in part of limestone cobbles, is about one foot thick. This is overlain in ascending order by gray platy siltstone, clay-ironstone, underclay, coal, light gray to dark gray to black, fissile to laminated shale. A composite section by Branson (Reed, Schoff, and Branson, 1955, p. 64) shows the total thickness of the Hartshorne formation to be about 38 feet:

	Thickness (feet)
Hartshorne formation	
Riverton coal	0-0.8
Underclay	1.5
Shale, dark gray to black, fissile	19.0
Clay-ironstone, calcareous, fossiliferous	0.7
Shale, dark gray, laminated to fissile	8.0
Siltstone, gray, platy, carbonaceous, with *Taonurus*	3.6
Shale, light gray, silty	0.8
Coal	0.3
Underclay	2.2
Conglomerate, limestone cobbles in part	1.2

In the same publication, Branson (pp. 65-67) says of the McAlester formation:

The McAlester formation of the platform is a much thinner equivalent of the formation in the type area near McAlester. The basal unit there is the McCurtain shale member, a dark shale up to 150 feet thick. This shale can be no more than inches thick in Ottawa County, and for mapping purposes the base of the Warner sandstone member is regarded as the base of the McAlester formation. The remarkably uniform sandstone called the Warner has been traced into Ottawa County from the type locality near Warner.

The rocks of the McAlester formation above the Warner sandstone member are dark gray to black, laminated to fissile shales with layers of clay-ironstone concretions, and with three coal zones, one of which is represented only by the underclay. These beds can be seen in the east bank of the Neosho River above Steppe Ford bridge in the drag zone on the downthrown side of the Steppe Ford fault. The locality is in the center of the south half of the part of irregular sec. 5 on the north side of the river in T. 28 N., R. 22 E. The strata exposed here as measured by the writer in July 1953 are:

	Thickness (feet)
McAlester or basal Savanna formation	
Shale, black, fissile, with clay-ironstone lenses	11.5
McAlester formation	
Coal	0.2
Underclay	2.3
Shale, black, fissile, with layers of clay-ironstone concretions	22.9
Underclay	1.2
Siltstone, light buff, platy, with *Taonurus*	0.6
Shale, black, fissile	0.8
Coal	0.2
Underclay	1.6
Warner sandstone member	9.5

A measured section[1] in the southern platform area follows:

		Feet (Approximate)
Savanna fm.	Spaniard limestone	2.0
	Underclay	1.0
	Gray shale	5.0
McAlester fm.	Sandstone, calcareous, fossiliferous	3.0
	Gray shale	7.0
	Shale, calcareous, fossiliferous	0.6
	Coal	0.4
	Underclay	1.5
	Micaceous shale	3.0

[1] C. C. Branson, Unpublished Notes. February, 1955.

TABLE I

	McALESTER BASIN	SOUTHERN PLATFORM	NORTHERN PLATFORM
SAVANNA FORMATION	SPANIARD LIMESTONE	SPANIARD LIMESTONE	
McALESTER FORMATION	SHALE	SHALE	SHALE
	KEOTA SANDSTONE		COAL
	SHALE		SHALE
	TAMAHA SANDSTONE	SANDSTONE	COAL
	SHALE	SHALE	SHALE
	CAMERON SANDSTONE		
	SHALE, STIGLER COAL	COAL	COAL
	LEQUIRE SANDSTONE		
	SHALE		SHALE
	WARNER SANDSTONE	WARNER SANDSTONE	WARNER SANDSTONE
	McCURTAIN SHALE	McCURTAIN (?) SHALE	
HARTSHORNE FORMATION	U. HARTSHORNE COAL	U. HARTSHORNE COAL	U. HARTSHORNE COAL
	UNDERCLAY	UNDERCLAY	UNDERCLAY
	SANDSTONE, SHALE		SHALE
			SILTSTONE
	L. HARTSHORNE COAL	COAL	COAL
	UNDERCLAY	UNDERCLAY, SHALE	UNDERCLAY
	TOBUCKSY SANDSTONE		CONGLOMERATE

The Spaniard limestone in the southern platform area of Wagoner County, northern Muskogee County, and southern Rogers and Mayes Counties, is characterized by *Fusulina novamexicana* and by numerous specimens of *Caninia.* The Spaniard is the basal member of the Savanna formation and serves as a marker by which the coals beneath can be placed in the section.

Newell (Wilson and Newell, 1937, p. 181) gives the following measured section of the McAlester formation in sec. 7, T. 15 N., R. 19 E., Muskogee County, Oklahoma:

	Feet
McAlester shale [formation]	
Warner sandstone member	
Sandstone, massive and slabby	20.0
McCurtain shale member	
Shale, dark, silty, with ironstone concretions, impressions of fossil clams at base	9.5
Coal	0.4
Underclay	0.3
Shale, silty, with ironstone concretions	10.0

Table I shows the subdivisions of the McAlester and Hartshorne formations in a comparison of the McAlester basin area with the southern and northern platform areas.

The Stigler Area. The Stigler coal area of Haskell, McIntosh, Sequoyah, and Muskogee Counties occupies part of a large geosyncline and lies in the depositional feature known as the McAlester basin located in east-central Oklahoma. The rocks of the McAlester basin consist of sedimentary rocks (thousands of feet thick in the central part of the basin) indicative of shallow-water deposition. The presence of numerous coal seams in the strata indicates recurrent marshy conditions. The basin is bounded on the northeast by the south flank of the Ozark uplift and on the north by the platform area, which occupies a large part of northeastern Oklahoma, and over which lies the thin, more completely marine facies. On the west, the basin is bounded by the subsurface structural feature north of the Arbuckle Mountains known as the central Oklahoma uplift, and on the south, by the Arbuckle Mountains and the Choctaw fault.

Subdivisions of the Krebs group of the Des Moines series in Haskell County are listed by Oakes and Knechtel (1948, p. 17):

Des Moines series
- Boggy formation
  - Strata above the Bluejacket sandstone member
  - Bluejacket sandstone member
- Savanna formation
- McAlester formation
  - Unnamed shale member
  - Keota sandstone member
  - Unnamed shale member
  - Tamaha sandstone member
  - Unnamed shale member [Stigler coal bed in basal part]
  - Cameron sandstone member
  - Unnamed shale member
  - Lequire sandstone member
  - Unnamed shale member
  - Warner sandstone member
  - McCurtain shale member
- Hartshorne sandstone [formation]
- Atoka formation

The Cameron sandstone member, the first sandstone below the shale containing the Stigler coal, is described by Oakes and Knechtel (1948, pp. 40-41) and Wilson (1937, pp. 41-42) as a fine-grained, ripple-marked, buff, unfossiliferous sandstone. Generally the Cameron sandstone is a resistant, well defined unit, but at places it is represented by a resistant sandstone separated from the Lequire by a few feet of softer, silty sandstone, and at other places the Cameron consists apparently of two thin blocky sandstone beds separated by about 10 feet of sandy shale. At still other places it is made up chiefly of thin beds of sandstone with some interbedded shale.

The shale overlying the Cameron sandstone contains the Stigler coal near the base. The coal ranges in thickness from a thin, knife-edge streak to nearly 2 feet, and invariably overlies an underclay. Toward the northern part of the Muskogee-Porum area the coal becomes thin and obscure so that its identification is uncertain (Wilson, 1937, p. 42.)

The Stigler coal in Haskell County is described by Oakes and Knechtel (1948, p. 41) as follows:

> The Stigler coal lies a few feet above the Cameron sandstone member wherever the Cameron is present in Haskell County. In areas where the Lequire sandstone member is thickest and may include in its upper few feet beds equivalent to the Cameron, the Stigler coal lies only a few feet above. In other localities, where the Lequire is unusually thin, and the Cameron is missing as in the abandoned strip pit in the SW¼ sec. 34, T. 8 N., R. 19 E., the Stigler coal lies in shale as much as 80 feet above the Lequire. As the coal is generally only a few feet above the Cameron its outcrop may be taken as indicating approximately the horizon of the Cameron . . . .

The Stigler coal bed underlies the greater part of western Haskell County. The outcrop extends from near Whitefield eastward along the north flank of the Whitefield uplift to the western environs of Stigler (Oakes and Knechtel, 1948, p. 85). The Stigler coal bed has been tentatively correlated in northern LeFlore County with the McAlester coal bed of areas farther south and west (Knechtel, 1949, p. 48).

The McAlester Area. The McAlester formation in the McAlester area ranges in thickness from 1,904 to 2,420 feet, but the apparent thickness varies greatly at several places. The formation may be divided into lower, middle, and upper parts and is described by Hendricks (1937, pp. 13-14) as follows:

> . . . The lower part consists mostly of shale, which measures about 500 to 640 feet in thickness. It contains the Upper Hartshorne coal bed 1 to 50 feet above the base and local thin beds of sandstone and coal in the lower 350 feet. The shale is uniformly dark, firm, and platy and contains numerous clay-ironstone concretions . . . .
>
> . . . .
>
> The upper portion of the formation is made up of shale that includes several lenticular sandstones, some coal, and two thin beds of very argillaceous limestone. The thickness of this upper portion of the formation ranges from about 300 to about 925 feet . . . The base of this portion of the McAlester has been placed at the top of the first sandstone below the McAlester coal. The McAlester coal lies only a few feet above this sandstone in the southern part of the district, but near McAlester the interval between the two is as much as 100 feet . . . . The shale is dark and carbonaceous in general, but locally beds of lighter-gray sandy shale were noted . . . .

The thickness of the McAlester coal ranges from about 1.5 to 4 feet; the average thickness where it has been mined is about 3.5 feet. The coal lies 1,400 to 1,600 feet above the base and 300 to 1,000 feet below the top of the McAlester formation. The distance of the coal bed above the top of the highest bed of the sandstone group near the middle of the McAlester formation varies from about 2 to 100 feet.

The top of the McAlester coal is overlain by firm shale or "slate". The coal generally overlies either firm shale or underclay. More partings (normally thin bands of pyrite) and bands of impurities occur in the McAlester coal than in the Upper and Lower Hartshorne coal beds—as many as seven partings have been recorded in a single section (Hendricks, 1937, pp. 56-57).

DESCRIPTIONS OF SPECIES

Introductory Statement

In identifying spores under the microscope it is necessary to examine a rather large number of specimens of the same type in order to understand possible variations and differences of appearance depending on the nature of preservation. The writer has included a number of illustrations with the hope that they may aid others in understanding which features are characteristic and which features are variations due to other causes, although illustrations at their best are sometimes misleading and cannot compare with the direct observation of the microfossil through the microscope. Certain types of spores are commonly compressed in a given plane, but some specimens of the same types may be flattened in a different direction, which results in a considerably different appearance. Specimens may be etched by over-maceration, broken, completely or partially stripped of characteristic ornamentation, or distorted by adjacent minerals or other hard foreign matter. Specimens of some species are consistently incompletely preserved, while those of other species are just as consistently complete and well preserved. Conditions of illumination and focus during observation may also result in apparent variations in spore features. Crawshay, in his work *The Spore Ornamentation of the Russulas* (1930, pp. 31-32) gives much pertinent observation and proceeds with a comprehensive discussion of the optical systems of microscopes and their proper applications. This writer strongly advocates a careful and thorough study of Crawshay's treatise.

The acquisition of an adequate, simple, and direct vocabulary to discuss or describe fossil spores is desirable. Spores may usually be classed in either of two principal forms (Cross, 1947, pp. 291-292): 1) bilaterally symmetrical; a slightly elongate shape rather like a bean in outline with a single slit-like opening running lengthwise, called the monolete aperture, and 2) radially symmetrical spores, commonly marked on one surface with a three-rayed slit, the trilete aperture or triradiate tetrad scar. This scar is the result of development of these spores in tetrahedral groupings. Bilateral spores normally develop in linear or cruciform series of four.

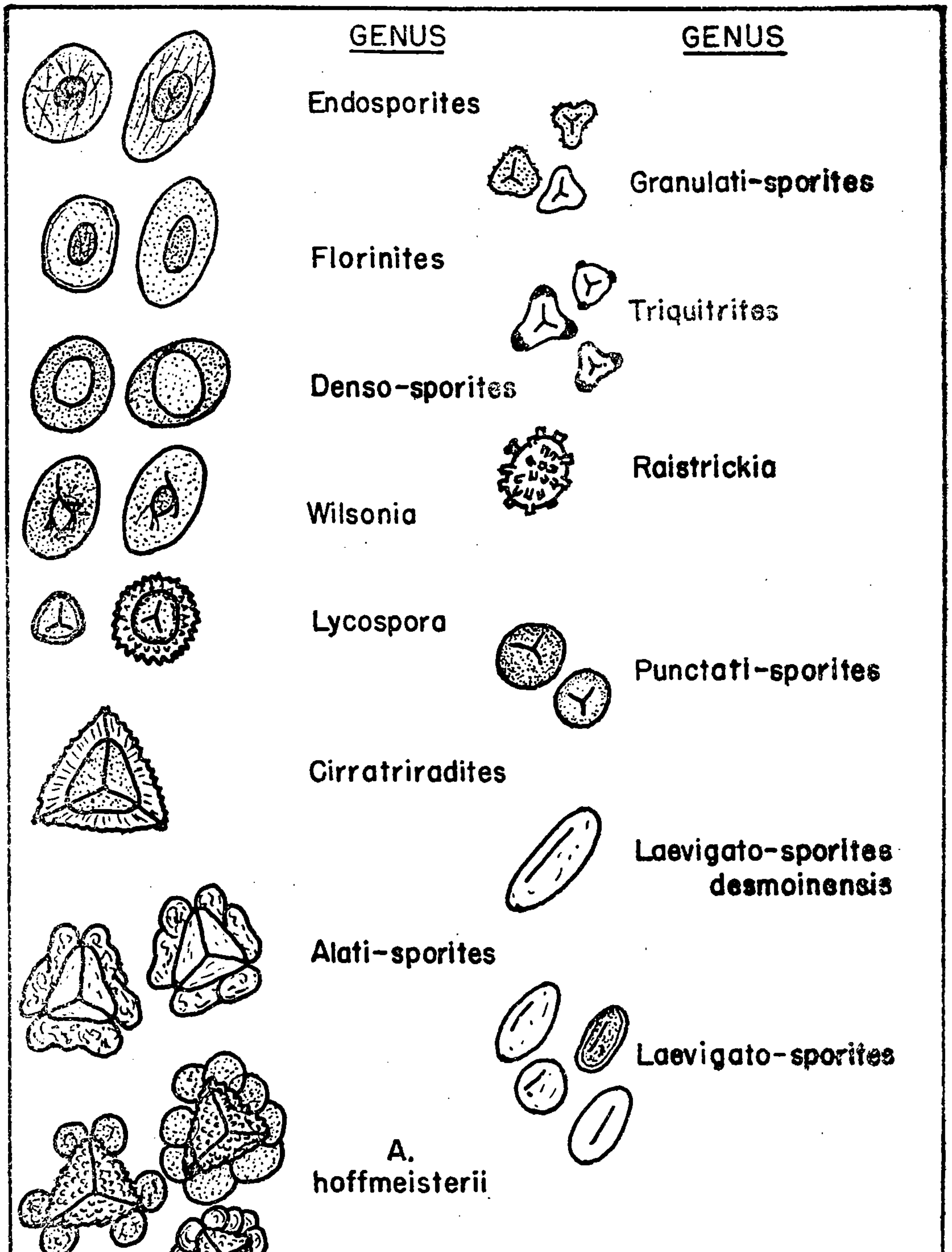

GENUS
GENUS
Endosporites
Granulati-sporites
Florinites
Triquitrites
Denso-sporites
Raistrickia
Wilsonia
Lycospora
Punctati-sporites
Cirratriradites
Laevigato-sporites desmoinensis
Alati-sporites
Laevigato-sporites
A. hoffmeisterii

FIG. I

Spores are commonly oriented in a certain way for description and comparative studies. The proximal side of radially symmetrical spores bears the triradiate scar and is the inner side of the spore in relation to its original grouping. The outer or opposite half of the spore is known as the distal side. The slit or aperture forms at the edges of the contact areas between spores in the tetrad and is therefore sometimes called the "commissure". The edges of the opening are known as the commissure lips, or sometimes more simply as the "lips". The lips of the commissure may be thick and well developed forming definite ridges or they may be completely undeveloped and not detectable from the surrounding areas of the spore wall. The rays of the trilete mark may extend from the center or apex to the margin or equator of the proximal side, only a part of the distance to the margin, or completely beyond the margin of the spore body onto a peripheral flange. The contact areas between the rays of the tetrad scar are known as the "pyramic areas" and may often differ in texture from any remaining peripheral area on the proximal side of the spore body. Especially strong development of the peripheral flange at the ends of the trilete rays or angles of the spore body sometimes produce auriculate or "eared" spores. At the apex of some trilete spores the aperture or slit developing along the triradiate scar is the place of emanation of the gametophyte or plant developing from the spore.

DESCRIPTIONS

In the present study one new species, *Alati-sporites hoffmeisterii*, has been isolated from the Rowe coal of Wagoner County, Oklahoma. The species has thus far yielded three separate varieties based on the number, arrangement, and ornamentation of bladders, and shape of the spore body.

Alati-sporites hoffmeisterii new species

Plate II, Figures 1-8

The specific name *hoffmeisterii* is proposed in honor of Dr. William S. Hoffmeister for spores of the following character: Spores are radial, body is substriangular in outline, margins between radii are commonly slightly concave to convex, but may sometimes be rather strongly concave as shown in some of the specimens

(Plate II, fig. 2). The spore body has well rounded corners, the coat is verrucose and about three microns thick, the trilete mark extends almost (if not completely) to the margin of the body, and the lips of the commissure are not well developed. The known range of the spore body in the mean diameter is from 45 to 75 microns. The bladders vary in number from 7 to 11 and are in some specimens attached to opposite sides of the body, thus causing a duplication, as shown at the lower right corner of the spore in Figs. 4 and 4a, Plate II. Of the spores thus far studied, eight bladders is the most common number. The bladders may in some specimens cover one or more corners of the spore body. In Plate II, Fig. 7, the two lower corners are covered by bladders. In Plate II, Figs. 2 and 6 the top corner is covered. The bladders are circular to ovate to elongate in outline, levigate to finely granulose, about one micron thick, and overlap the spore body by as much as 16 microns. The spores are commonly flattened in fair proximal-distal orientation.

Specimens of the species superficially resemble *Alati-sporites punctatus* Kosanke, which has only three bladders but gives the illusion of more than three due to strong folding. By focusing up and down, the existence of only three bladders in *A. punctatus* and of more than three in specimens of *A. hoffmeisteri* may easily be ascertained. The bladders of *A. hoffmeisteri* are normally smooth in outline as contrasted to those of *A. punctatus,* which are commonly irregular due to folding. Bladders of other species of the genus *Alati-sporites* are situated along the interradial margins of the body and the corners are never covered, although they may sometimes appear so due to overlapping of the ends of the bladders.

Holotype. Sample XI, Slide D-54a: H-149.5; V-112.2, Rowe coal, Wagoner County, Oklahoma.

The typical variety is illustrated in Plate II, Figs. 1, 5-8. Spores are radial, body is subtriangular in outline, interradial margins are commonly slightly convex, but one or more sides may be slightly concave. The body has well rounded corners, the trilete ray extends at least eight tenths of the distance to the spore wall, the coat is verrucose, and the commissure lips are not developed. The over-all measurement of the holotype is 98 microns and the spore body is 66 x 69 microns. The bladders vary in number from 7 to 11, are finely granulose, and commonly show wrinkles radiating outward from the spore wall.

A second variety is shown in Plate II, Figure 2. Spores are radial, body is subtriangular in outline, margins between radii are definitely concave to comparatively straight, and the corners are blunt to almost flat. The tetrasporic mark extends almost to the margin of the spore and is indistinct. The lips of the commissure are poorly developed. The best specimen has an over-all measurement of 75 x 82 microns; the mean diameter of the body is 45 microns. The spore coat is verrucose and about 3 microns thick. Seven overlapping bladders completely encircle the body of the holotype with one of the corners being covered directly (not by overlapping). The bladders are smooth (although they appear very finely granulose at about 720 magnification), arcuately wrinkled, and circular to ovate in outline.

Type. Sample X, Slide D-46: H-142.2; V-123.0, Rowe coal, Wagoner County, Oklahoma.

A third variant of the species is shown in Plate II, Fig. 3. Spores are radial, body is subtriangular in outline, interradial margins are convex to concave and partly uncovered by bladders near the mid-point between corners. The corners are well rounded, the commissure extends to the margin of the spore body, and the lips are not developed. The over-all measurement of the holotype is 101 microns; the body measures 67 x 70 microns. Six bladders occur in pairs at the corners of the spore (one bladder on each side of the trilete ray), plus an extra pair at the lower right corner making a total of eight. The paratype has an over-all measurement of 95 microns and a body diameter of 66 microns. Bladders occur in pairs at the corners of the spore as in the holotype, but an extra pair on the proximal side at the lower right corner plus one extra bladder on the proximal side at the other two corners raise the total number to ten.

Types. Sample X, Slide D-50a: H-140.6; V-127.0, Rowe coal, Wagoner County, Oklahoma.

Sample XI, Slide D-52: H-135.5; V-113.4, Rowe coal, Wagoner County, Oklahoma.

Correlations

Seventeen types of spores were counted for the preparation of histograms for correlation purposes. Most of the seventeen types are by genera, but *Granulati-sporites* (Ibrahim, 1933) emend., Schopf, Wilson, and Bentall, 1944 was divided into two groups on the basis of whether granulose or levigate, and the genus *Laevigato-sporites* (Ibrahim, 1933) emend., S., W., and B., 1944, was divided into four groups or species on the basis of shape: 1) *L. desmoinensis* (Wilson and Coe) S., W., and B., and related elongate forms; 2) *L. sp.* Wilson and Hoffmeister (MSS Form), and related forms circular in outline; 3) *L. ovalis* Kosanke, and related ovate forms; and 4) *L. minutus* (Ibrahim) S. W. and B., and related small punctate forms oval in outline having a thick coat. The choice of the last named was unfortunate in that a number of spores taken for *L. minutus* on cursory examination while counting, proved later to be levigate forms etched during maceration. For that reason, in examining the histograms for correlatives, the third column from the right, which represents this group, should be disregarded. Figure 1 shows the genera used in making up the histograms.

The histograms are assigned the same number as the locality number with the exception of the composite histogram of samples Ia, Ib, and Ic. The composite graph is designated as I_m.

The histogram I_m, representing the McAlester coal from the Lone Star Steel Company's Carbon Mine No. 5, bears a close resemblance, as it should, with histogram II which represents the McAlester coal collected in random chunks from the spoils heap of an old strip pit about 1.5 miles northwest of locality I. Histogram III represents the Stigler coal from the type area east of Whitefield (west of Stigler) and also closely resembles the composite chart I_m, showing excellent correlation of the Stigler and McAlester coals. This is not surprising for the McAlester coal and the Stigler coal have long been thought to be one and the same seam of coal.

No histograms are included for localities IV, V, VI, and VII, since the coal from these localities did not yield identifiable spores, although cuticle was abundant along with many blackened shapes indicative of spores. In an effort to isolate spores from these

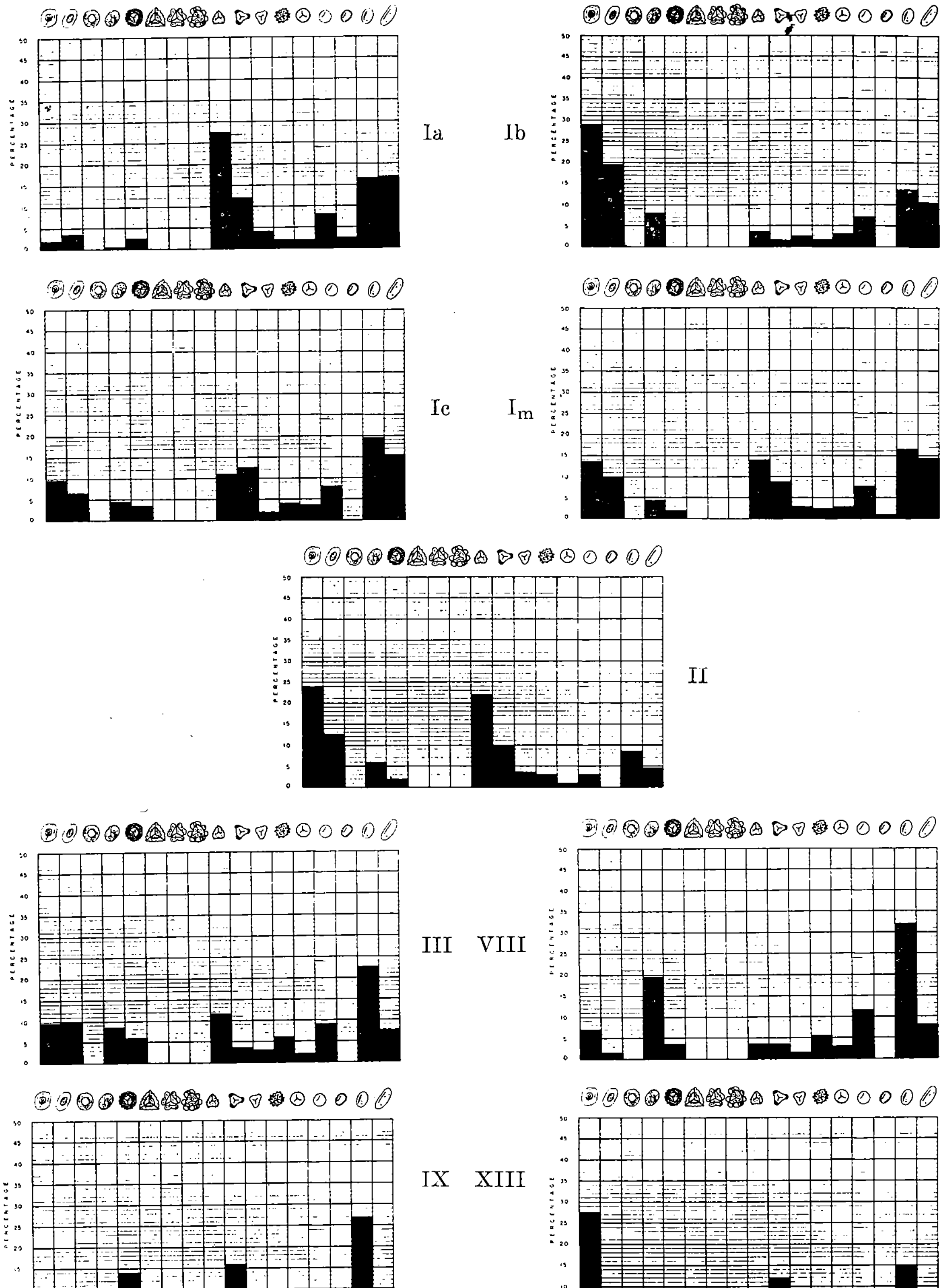

Ia
Ib
Ic
Im
II
III
VIII
IX
XIII
PERCENTAGE
0
5
10
15
20
25
30
35
40
45
50

Fig. 2

samples, an experiment with a sample of the Riverton coal (locality XV), which was known to contain spores in abundance, gave an indication as to a possible reason for inability to liberate spores by maceration.

About 15 grams of pulverized Riverton coal was placed in an electric furnace and heated to a temperature of 400° C. in the absence of oxygen. The coal was held at this temperature for a period of two hours then cooled slowly until the temperature was well below the combustion point. The coal was then removed from the furnace and allowed to cool to room temperature. Maceration techniques similar to those carried out on the unproductive samples were applied to the Riverton sample, and in each case the results were the same as the macerations of the unproductive samples, with the exception of a paucity of cuticle. The same blackened shapes resembling spores were present in each case. This experiment suggests the possibility that the coal from these localities has at some time been subjected to temperature and pressure sufficient to destroy the spores, but insufficient to produce recognizable metamorphism. All these localities are within the 77.5 isocarb of T. A. Hendricks (1939, p. 296), while all the productive samples in the surrounding region are in the area with a fixed carbon ratio of less than 70. Therefore, some degree of metamorphism is indicated where the spores have been destroyed. Another factor is that each of these unproductive samples was obtained from localities of major faulting. Sample V is from a coal seam south of the Mulberry fault; the other three samples (IV, VI, and VII) are from localities near lesser known faults. (Note the grouping of these sample localities on the location map.)

Histogram VIII represents the Stigler coal from north of Keefeton, in Muskogee County, Oklahoma, and shows the same general pattern as the composite chart I_m.

The second coal below the Spaniard limestone from the area south of the city of Muskogee is represented by graph IX. This graph shows a close rememblance to histograms I_m, II, III, and VIII, even though a trace of *Denso-sporites* is noted in column three. Histogram XIII represents the coal eight feet below the Spaniard limestone (the second coal below) west of Pryor, Oklahoma. This histogram also correlates with those of the McAlester and Stigler coals. A mere trace of *Cirratriradites* occurs in XIII which does now show in IX, and the trace of *Denso-sporites* shown in graph IX does not appear in XIII. These are minor variations and could easily happen in two histograms made from different slides of the same maceration. The absence of a bar on the graph representing a genus does not necessarily mean that that particular genus is absent in the coal sample. This is especially true if some other species or genus being counted is abundant, for then the chances of the rare genus being represented in the count are lessened. On the other hand, the appearance of a few spores of a particular type on one slide does not insure they will be found on other slides of the same sample. Naturally, the percentage bar on the chart representing the most abundant type of spore will be the most accurate, while the bar representing the rarest type will be the least accurate representation of the coal sample. Hence, the coals represented by graphs IX and XIII are correlated with the McAlester-Stigler coal.

Histogram X represents the Rowe coal from sec. 33, T. 17 N., R. 18 E., Wagoner County, Oklahoma. Histogram XI is for the Rowe coal from sec. 6 of the same township. A comparison of these two charts shows a similarity in that *Endosporites* is absent and that *Alati-sporites hoffmeisterii* makes a good showing on both. These variations are significant in that *Endosporites* is represented in all coals thus far mentioned that correlate with the McAlester or Stigler coal, and in the fact that *A. hoffmeisterii* was found in no other samples. Although *Alati-sporites* is absent on chart X, the genus is known to be in that sample, having been noted in previous examinations of the microslides. This is an example of the situation just mentioned where the absence of a bar on the graph does not mean that the genus is entirely missing from the sample, although it does indicate that the type of spore is rare. This is also true of *Triquitrites,* which is probably over-represented in histogram XI due to the fact that a cluster of 11 spores of that genus was found while making the count for that coal sample. Thus, these two histograms show a correlation between themselves, but do not correlate with the others. The granulose form of *Granulati-sporites* is absent in these two histograms alone, and the levigate form makes only a minor showing.

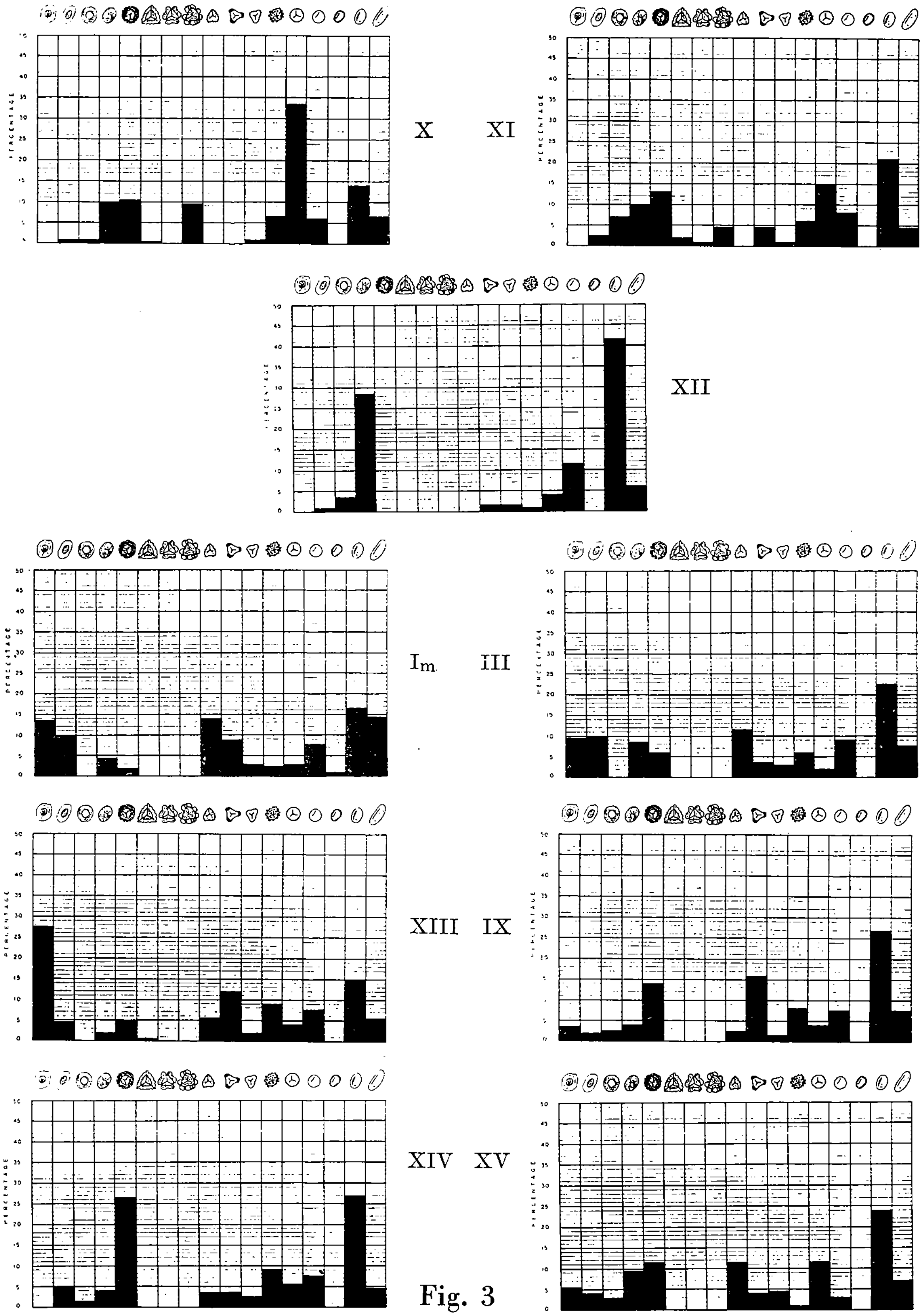


Fig. 3

The coal at the base of the Spaniard limestone from the locality west of Pryor, Oklahoma, is represented by histogram XII. This graph is unlike all the others, as it should be, for the bed of coal which it represents is lower in the section than the Rowe coal and higher than the Riverton and the coal 8 feet below the Spaniard limestone.

Histograms XIII and IX are placed beneath I_m and III respectively to show better their inter-correlation.

The upper coal bed of the Steppe Ford section west of Miami, Oklahoma, is represented by histogram XIV, which superficially resembles graph XII. A careful inspection of the two charts reveals several notable differences: *Wilsonia* is abundant (28.5 percent) in XII, while *Lycospora* and the granulose form of *Granulati-sporites* are absent; in graph XIV, the granulose form of *Granulati-sporites* is present (3.5 percent), *Lycospora* is abundant (26.5 percent), and *Wilsonia* is only 4.0 percent of the flora. The coal represented by histogram XIV does not correlate with any of the other coals represented.

Histogram XV represents the Riverton coal from the locality in southeastern Kansas. This graph is similar to IX (representing the second coal below the Spaniard limestone) which has been shown by this study to correlate with the McAlester-Stigler coal. A careful comparison of these two graphs, however, reveals certain differences. Histogram IX shows an abundance of *Triquitrites* (16.0 percent) as compared to only 4.0 percent in chart XV. The granulose form of *Granulati-sporites* is rare (3.0 percent) in IX, but is common (11.5 percent) in histogram XV. The round form of *Laevigato-sporites,* fairly well-represented in correlatives of the McAlester-Stigler coal, is comparatively rare (3.0 percent) in the Riverton, and the levigate form of *Granulati-sporites* is more common (4.5 percent) in XV than in any other histogram shown. Thus the Riverton coal, which is lower in the section than the McAlester-Stigler coal, is different in spore population and does not correlate with any of the other coals studied.

REFERENCES

Alexander, R. D., 1954, "Desmoinesian fusulinids of northeastern Oklahoma", *Okla. Geol. Survey, Circ.* 31, pp. 5-67.

Bailey, W. F., 1935, "Micropaleontology and stratigraphy of the lower Pennsylvanian of Central Missouri", *Jour. Paleont.*, Vol. 9, pp. 483-500.

Barkeley, F. A., 1934, "The statistical theory of pollen analysis", *Ecology*. Vol. 15, pp. 283-289.

Bennie, J. and Kidston, R., 1886, "On spores in the Carboniferous formation of Scotland", *Royal Phys. Soc. Edinburgh, Proc.*, Vol. 9, pp. 82-117.

Bowman, P. W., 1931, "Study of a peat bog near the Matamek River, Quebec, Canada, by the method of pollen analysis", *Ecology*, Vol. 12, pp. 694-708.

————, 1934, "Pollen analysis of Kodiak bogs", *Ecology*, Vol. 15, pp. 97-100.

Branson, C. C., 1954, "Field conference on Desmoinesian rocks of northeastern Oklahoma", *Okla. Geol. Survey, Guide Book* II, 41 pp.

Cain, S. A., 1939, "Pollen analysis as a paleo-ecological research method", *Botanical Review*, Vol. 5, pp. 627-654.

Camp, C. L. and Hanna, G. D., 1937, *Methods in Paleontology*, Berkeley: The Univ. of Calif. Press, 132 pp.

Chrisman, L. P., 1951, "The geology of the Big Cabin Creek area, Craig County, Oklahoma", Unpublished Master of Science Thesis, University of Oklahoma, 66 pp.

Claxton, C. D., 1952, "The geology of the Welch area, Craig County, Oklahoma", Unpublished Master of Science Thesis, University of Oklahoma, 43 pp.

Crawshay, R., 1930, *The Spore Ornamentation of the Russulas*, London: Bailliere, Tindall, and Cox, pp. 31-175.

Cross, A. T., 1947, "Spore floras of the Pennsylvanian of West Virginia and Kentucky", *Jour. Geology*, Vol. 55, pp. 285-308.

———— and Schemel, M. P., 1952, "Representative microfossil floras of some Appalachian coals", *Troisième Congrès pour l'Avancement des Études de Stratigraphie et de Géologie du Carbonifère*, Heerlen, 1951, *Compte Rendu*, Tome I, pp. 123-130.

Darrah, W. C., 1937, "Spores of Cambrian plants", *Science*, Vol. 86, pp. 154-155.

————, 1952, "The materials and methods of palaeobotany", *The Palaeobotanist*, Vol. 1, pp. 145-151.

Dijkstra, S. J., 1952, "The stratigraphical value of megaspores", *Troisième Congrès pour l'Avancement des Études de Stratigraphie et de Géologie du Carbonifère*, Heerlen, 1951, *Compte Rendu*, Tome I, pp. 163-167.

Draper, P. I., 1928, "A demonstration of the technique of pollen analysis", *Okla. Acad. Sci., Proc.*, Vol. 8, pp. 63-64.

————, 1929, "Pollen spectra of post glacial Ohio bogs of various ages", Unpublished Master of Science Thesis, University of Oklahoma, 26 pp.

Erdtman, G., 1931a, "The boreal hazel forests and the theory of pollen statistics", *Jour. Ecology*, Vol. 19, pp. 158-163.

————, 1931b, "Pollen statistics; a new research method in paleo-ecology", *Science*, Vol. 73, pp. 399-401.

————, 1943, *An Introduction to Pollen Analysis*, Waltham, Mass.: The Chronica Botanica Co., 227 pp.

————, 1952a, "On pollen and spore terminology", *The Palaeobotanist*, Vol. 1, pp. 169-176.

————, 1952b, *Pollen Morphology and Plant Taxonomy; Angiosperms*, Waltham, Mass.: The Chronica Botanica Co., pp. 3-472.

Erdtman, G. and Erdtman, H., 1933, "The improvement of pollen-analysis technique", *Svensk Botanisk Tidskrift*, Vol. 27, pp. 347-356.

Florin, R., 1936, "On the structure of the pollen grains in the Cordaitales", *Svensk Botanisk Tidskrift*, Vol. 30, No. 3, pp. 624-651.

————, 1937, "On the morphology of the pollen grains in some Palaeozoic Pteridosperms", *Svensk Botanisk Tidskrift*, Vol. 31, No. 3, pp. 305-338.

Fuller, G. D., 1927, "Pollen analysis and postglacial vegetation", *Botanical Gazette*, Vol. 83, pp. 323-325.

————, 1929, "Peat bogs and postglacial vegetation", *Botanical Gazette*, Vol. 87, pp. 560-562.

Furrer, E., 1927, "Pollenanalytische Studien in der Schweiz", *Beiblatt zur Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich*, Jahrg. 72, No. 14, pp. 1-38.

Godwin H., 1934, "Pollen analysis. An outline of the problems and potentialities of the method", *New Phytologist*, Vol. 33, pp. 278-304.

————, 1941, "Pollen analysis and Quaternary geology", *Geologists Assoc. London, Proc.*, Vol. 52, pp. 328-361.

Gruman, W. P., 1954, "Geology of the Foyil area, Rogers and Mayes Counties, Oklahoma", Unpublished Master of Science Thesis, University of Oklahoma, 84 pp.

Hendricks, T. A., 1937, "Geology and fuel resources of the southern part of the Oklahoma coal field, part 1—the McAlester district", *U. S. Geol. Survey. Bull.* 874-A, pp. 1-87.

————, 1939, "Geology and fuel resources of the southern part of the Oklahoma coal field, part 4—the Howe-Wilburton district, Latimer and LeFlore Counties", *U. S. Geol. Survey, Bull.* 874-D, pp. 255-298.

Kidston, R., 1905, "On the microsporangia of the Pteridospermeae, with remarks on their relationship to existing groups", *Royal Soc. London, Philos. Trans.*, Ser. B, Vol. 198, pp. 413-446.

Knechtel, M. M., 1949, "Geology and coal and natural gas resources of northern LeFlore County, Oklahoma", *Okla. Geol. Survey, Bull.* 68, pp. 7-71.

Knox, E. M., 1942, "The microspores in some coals of the productive coal measures in Fife", *Inst. Min. Engin., Trans.*, Vol. 101, pp. 98-112.

————, 1952, "The microspores of some Scottish coals, and their vertical distribution", *Troisième Congrès pour l'Avancement des Études de Stratigraphie et de Géologie du Carbonifère*, Heerlen, 1951, *Compte Rendu*, Tome I, pp. 333-334.

Kosanke, R. M., 1947, "Plant microfossils in correlation of coal beds", *Jour. Geology*, Vol. 55, pp. 280-284.

————, 1950, "Pennsylvanian spores of Illinois and their use in correlation", *Ill. Geol. Survey, Bull.* 74, pp. 7-125.

Kremp, G., 1952, "Sporen-Vergesellschaftungen und Mikrofaunen-Horizonte im Ruhrkarbon", *Troisième Congrès pour l'Avancement des Études de Stratigraphie et de Géologie du Carbonifère*, Heerlen, 1951, *Compte Rendu*, Tome I, pp. 347-357.

Lane, G. H., 1932, "A preliminary pollen analysis of the East McCulloch bog", Unpublished Master of Science Thesis, University of Oklahoma, 21 pp.

Lewis, I. F. and Cocke, E. C., 1930, "Pollen analysis of Dismal Swamp peat", *Elisha Mitchell Scientific Soc., Jour.*, Vol. 45, pp. 37-58.

Lohman, C., Jr., 1952, "Geology of the Whiteoak area, Craig and Rogers Counties, Oklahoma", Unpublished Master of Science Thesis, University of Oklahoma, 89 pp.

Lontos, J. T., 1952, "Geology of the Coweta area, Wagoner, Muskogee, and Okmulgee Counties, Oklahoma", Unpublished Master of Science Thesis, University of Oklahoma, 55 pp.

Luber, A. A., 1937, "Methods for correlating the coal seams of the Palaeozoic basins according to spores", *17th International Geol. Congr.*, Abstracts of Papers, Moscow, p. 61.

Meinke, H., 1927, "Atlas und Bestimmungsschlüssel zur Pollenanalytik", *Botanisches Archiv,* Band 19, pp. 380-449.

McCabe, L. C., 1931, "Some plant structures of coal", *Ill. State Acad. Sci., Trans.,* Vol. 24, No. 2, pp. 321-326.

Naumova, S. N., 1937, "The spores and pollen of the coals of the USSR", *17th International Geol. Congr.,* Abstracts of Papers, Moscow, pp. 60-61.

Oakes, M. C., 1944, "Broken Arrow coal and associated strata", *Okla. Geol. Survey, Circ.* 24, pp. 5-40.

——————— and Knechtel, M. M., 1948, "Geology and mineral resources of Haskell County, Oklahoma", *Okla. Geol. Survey, Bull.* 67, pp. 5-134.

Pierce, W. G. and Courtier, W. H., 1937, "Geology and coal reserves of the southeastern Kansas coal field", *Kans. Geol. Survey, Bull.* 24, pp. 7-122.

Potonié, R. and Kremp, G., 1954, "Die Gattungen der paläozoischen Sporae dispersae und ihre Stratigraphie", *Amt für Bodenforschung zu Hannover, Geol. Jahrb.,* Band 69, pp. 114-191.

Raistrick, A., 1934, "The correlation of coal seams by microspores", *Armstrong College Min. Soc., Jour.,* Vol. 10, pp. 14-22.

———————, 1937, "The microspores of coal and their use in correlation etc.", *Deuxième Congrès pour l'Avancement des Études de Stratigraphie Carbonifère,* Heerlen, 1935, *Compte Rendu,* Tome II, pp. 909-917.

Reed, E. W., Schoff, S. L., and Branson, C. C., 1955, "Groundwater resources of Ottawa County, Oklahoma", *Okla. Geol. Survey, Bull.* 72, pp. 9-190.

Schnarf, K., 1933, "Embryologie der Gymnospermen", *Handbuch der Pflanzenanatomie,* Vol. 10, Part 2, No. 2-E, 278 pp.

Schopf, J. M., 1938, "Spores from the Herrin (No. 6) coal bed in Illinois", *Ill. Geol. Survey, Report of Investigations* No. 50, pp. 5-73.

———————, Wilson, L. R., and Bentall, R., 1944, "An annotated synopsis of Paleozoic fossil spores and the definition of generic groups", *Ill. Geol. Survey, Report of Investigations* No. 91, pp. 7-73.

Sears, P. B., 1930a, "Common fossil pollen of the Erie basin", *Botanical Gazette,* Vol. 89, pp. 95-106.

———, 1930b, "A record of post glacial climate in northern Ohio", *Ohio Jour. Science,* Vol. 30, pp. 205-217.

———, 1931, "Pollen analysis of Mud Lake in Ohio", *Ecology,* Vol. 12, pp. 650-655.

———, 1932b. "Postglacial climate in eastern North America", *Ecology,* Vol. 13, pp. 1-6.

———, 1935b, "Types of North American pollen profiles", *Ecology,* Vol. 16, pp. 488-499.

——— and Couch, G. C., 1932, "Microfossils in an Arkansas peat and their significance", *Ohio Jour. Science,* Vol. 32, pp. 63-68.

———and Janson, E., 1933, "The rate of peat growth in the Erie basin", *Ecology,* Vol. 14, pp. 348-355.

——— and Galloway, E. F., 1937, "Microfossil succession in a bog in northern Wisconsin", *Ecology,* Vol. 18, pp. 113-118.

Singh, P., 1952, "Microfossils from an oil shale of Saline series in the Fatehpur Maira Gorge, Salt Range, Punjab", *The Palaeobotanist,* Vol. 1 ,pp. 417-419.

Smith, M. L., 1954, "A method of selecting sample sizes", *Jour. Paleontology,* Vol. 28, pp. 116-117.

Sprunk, G. C., Ode, W. H., Selvig, W. A., and O'Donnell, H. J., 1940, "Splint coals of the Appalachian region; their occurrence, petrography, and comparison of physical properties with associated bright coals", *U. S. Bur. Mines, Techn. Paper* 615, pp. 1-59.

Stach, E., 1949, *Lehrbuch der Kohlenmikroskopie,* Kettwig: Verlag Glükauf G. M. B. H., Band I, pp. 17-256.

Stark, P., 1925, "Der gegenwärtige Stand der Pollenanalytischen Forschung (Sammelreferat)" *Zeitschrift für Botanik,* Band 17, pp. 89-125.

Stutzer, O. and Noé, A. C., 1940, *Geology of Coal,* Chicago: The Univ. of Chicago Press, 422 pp.

Surange, K. R., Singh, P., and Srivastava, P. N., 1953, "Megaspores from the West Bokaro coalfield (Lower Gondwanas) of Bihar", *The Palaeobotanist,* Vol. 2, pp. 9-16.

Thiessen, R., 1920, "Structure in Paleozoic bituminous coals", *U. S. Bur. Mines, Bull.* 117, pp. 1-290.

———, 1925, "Microscopic examination of Kentucky oil shales", *Kentucky Geol. Survey,* Ser. 6, Vol. 21, pp. 1-47.

———, and Sprunk, G. C., 1936. "The origin of the finely divided or granular opaque matter in splint coals", *Fuel in Science and Practice,* Vol. 15, No. 11, pp. 304-315.

——————, Sprunk, G. C., and O'Donnell, H. J., 1931, "Microscopic study of Elkhorn coal bed at Jenkins, Letcher County, Ky.", *U. S. Bur. Mines, Techn. Paper* 506, pp. 1-30.

Tillman, J. L., 1952, "Geology of the Tiawah area, Rogers and Mayes Counties, Oklahoma", Unpublished Master of Science Thesis, University of Oklahoma, 56 pp.

Ware, H. E., Jr., 1954, "Surface and shallow subsurface investigation of the Senora formation of northeastern Oklahoma", Unpublished Master of Science Thesis, University of Oklahoma, 68 pp.

Wilson, C. W., Jr., 1937, "Geology of the Muskogee-Porum district, Muskogee and McIntosh Counties, Oklahoma", *Okla. Geol. Survey, Bull.* 57, pp. 6-184.

Wilson, E. B., Jr., 1952, *An Introduction to Scientific Research,* New York: McGraw-Hill, 365 pp.

Wilson, L. R., 1932, "The Two Greeks forest bed, Manitowoc County, Wisconsin", *Wisc. Acad. Science, Jour.,* Vol. 27, pp. 31-46.

——————, 1936, "Further fossil studies of the Two Creeks forest bed, Manitowoc County, Wisconsin", *Torrey Bot. Club, Bull.,* Vol. 63, pp. 317-325.

——————, 1944, "Spores and pollen as microfossils", *Botanical Review,* Vol. 10, No. 8, pp. 499-519.

Wilson, L. R., 1946, "The correlation of sedimentary rocks by fossil spores and pollen", *Jour. Sedimentary Petrology,* Vol. 16, No. 3, pp. 110-120.

—————— and Coe, E. A., 1940, "Descriptions of some plant microfossils from the Des Moines series of Iowa", *Amer. Midland Naturalist,* Vol. 23, pp. 182-186.

Witham, H. T. M., 1833, *The Internal Structure of Fossil Vegetables Found in the Carboniferous and Oolitic Deposits of Great Britain,* Edinburgh: Adam and Charles Black, and London: Longman, Rees, Orme, Brown, Green, and Longman, 84 pp.

Wodehouse, R. P., 1928, "The phylogenetic value of pollen grain characters", *Ann. Botany,* Vol. 42, pp. 891-934.

——————, 1935a, *Pollen Grains, Their Structure, Identification, and Significance in Science and Medicine,* New York: McGraw-Hill, 540 pp.

——————, 1935b, "Shapes of pollen grains", *Practical Microscopy,* Vol. 1, pp. 30-31.

Zerndt, Jr., 1930, "Megasporen aus einem Flöz in Libiaz (Stephanien)", *Bulletin International de l'Académie Polonaise des Sciences et des Lettres,* Serie B., No. 7, pp. 39-70.

Zeuner, F. E., 1952, *Dating the Past,* London: Methuen and Co. Ltd., 419 pp.

PLATE I

(All spores magnified 508 diameters)

Figures

1 *Endosporites vesicatus* Kosanke, 1950. Typical specimen from the coal 8 feet below the Spaniard limestone, locality XIII. Fig. 1: Slide D-78a; H-136.4; V-109.8.

2 *Endosporites* sp. Typical specimen from the McAlester coal, locality II. Fig. 2: Slide C-31; H-141.4; V-111.4.

3 *Florinites antiquus* Schopf, 1944, Slide D-57a; H-140.2; V-121.9, Rowe coal, locality XI.

4 *Florinites* sp. Typical specimen from the McAlester coal, locality II. Fig. 4: Slide C-37; H-138.5; V-110.5.

5 *Wilsonia* sp., Slide D-69; H-138.2; V-124.8, coal at base of the Spaniard limestone, locality XII.

6 *Lycospora punctata* (?) Kosanke, 1950, coal 8 feet below the Spaniard limestone, locality XIII. Fig. 6: Slide D-75a; H-147.2; V-113.0.

7 *Lycospora* sp. Typical specimen from the upper coal bed of the Steppe Ford section. Fig. 7: Slide D-81; H-145.6; V-107.8.

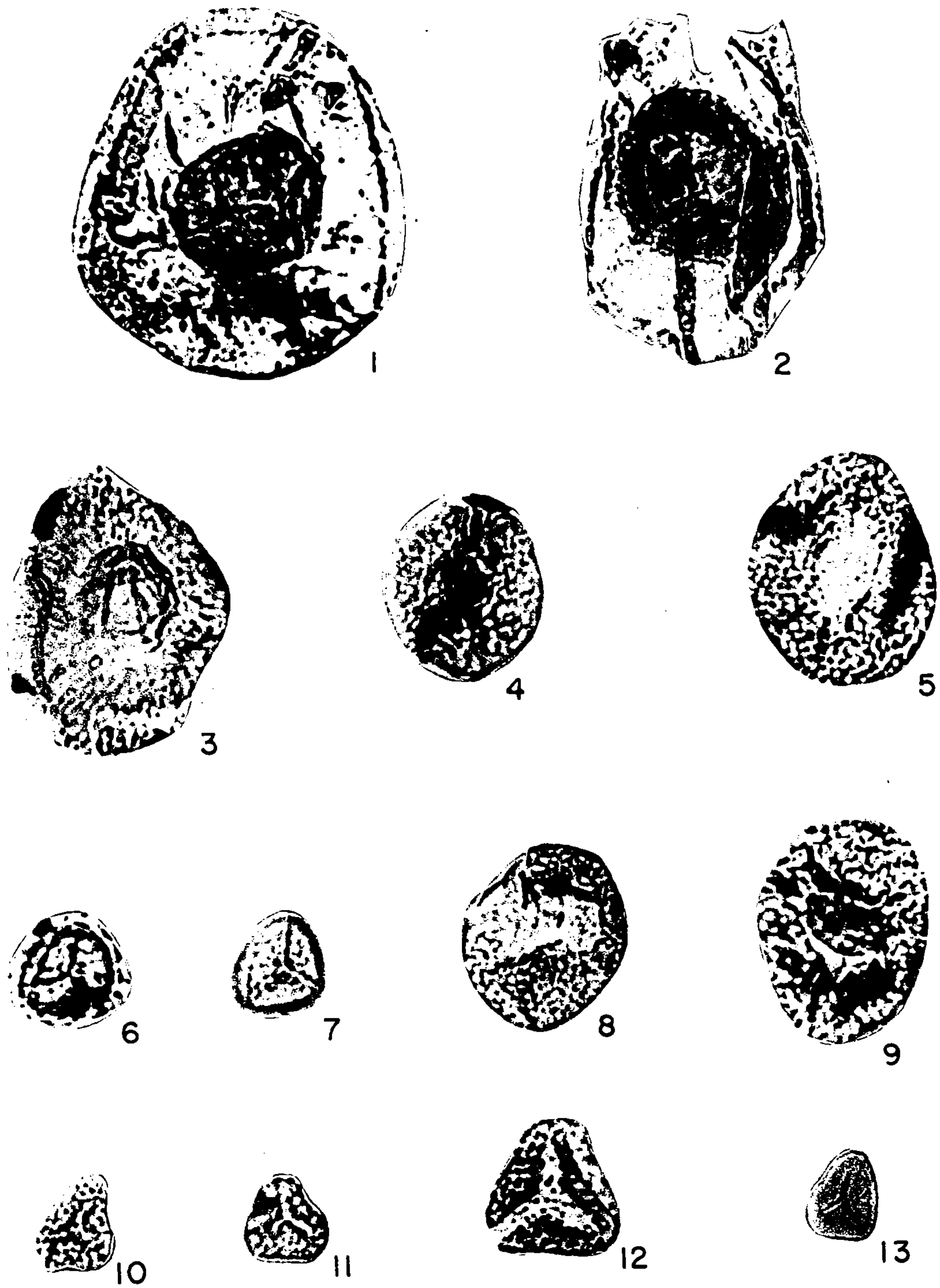
8-9 *Wilsonia* sp. Typical specimens from the Stigler coal, locality VIII. Fig. 8: Slide D-22; H-148.7; V-109.7 Fig. 9: Slide D-27; H-145.3; V-110.2.

10 *Granulati-sporites commissuralis* Kosanke, 1950, McAlester coal, locality II. Fig. 10: Slide C-37; H-138.1; V-109.9.

11 *G. granularis* Kosanke, 1950, Riverton coal, locality XV. Fig. 11: Slide B-51; H-152.9; V-115.4.

12 *Granulati-sporites* sp., Rowe coal, locality XI. Slide D-52a; H-149.0; V-115.8.

13 *G. adnatus* (?) Kosanke, 1950. From the McAlester coal, locality II. Slide C-32; H-142.1; V-113.9.


1
2
3
4
5
6
7
8
9
10
11
12
13

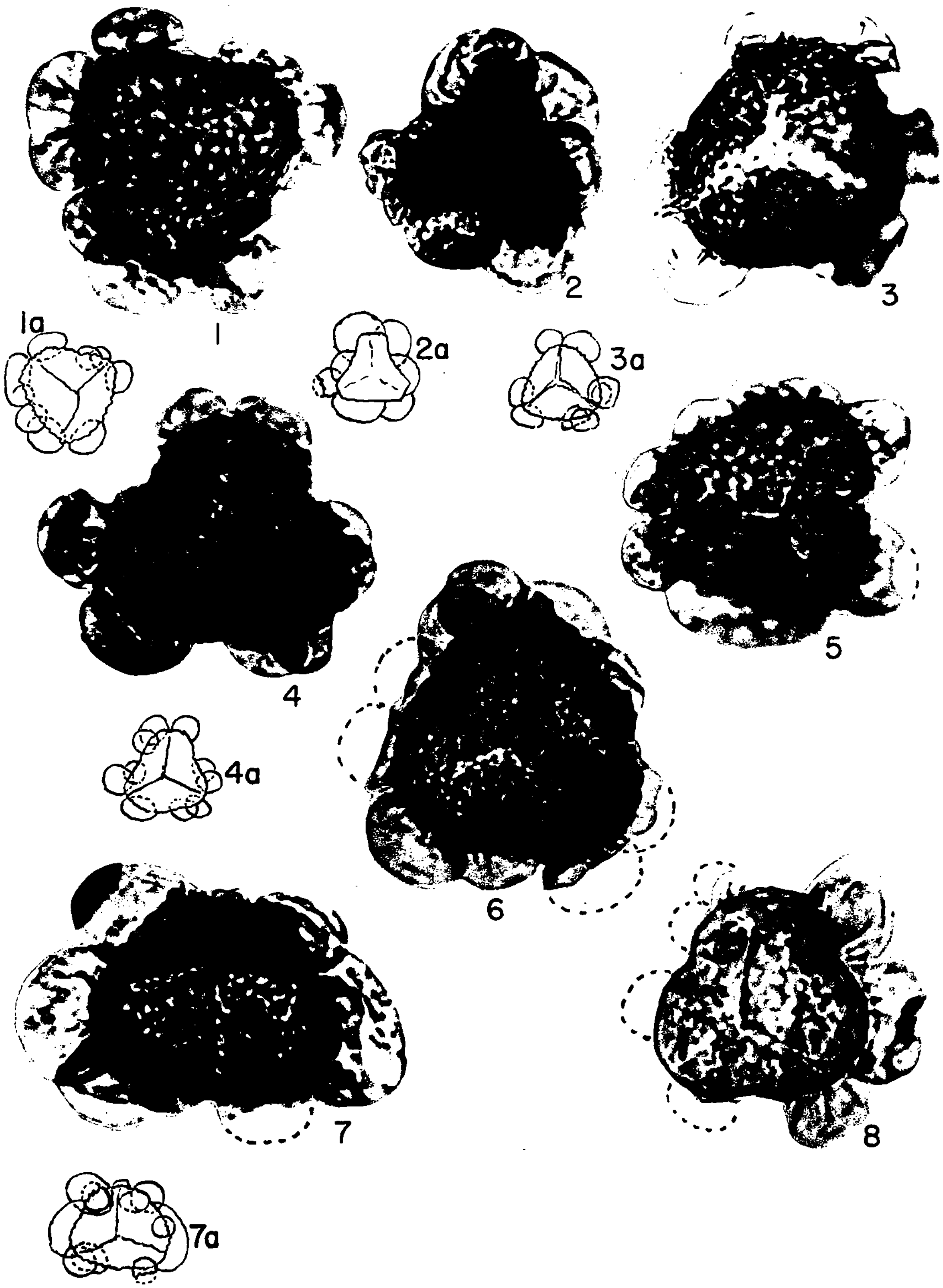

1
1a
2
2a
3
3a
4
4a
5
6
7
7a
8

PLATE II

(All spores magnified 508 diameters)

Figures

1 *Alati-sporites hoffmeisterii* new species, holotype, Slide D-54a; H-149.5; V-112.2, Rowe coal, locality XI. Fig. 1a shows positions of the 8 bladders. The long bladder at the upper left side has an arcuate fold near the bottom which gives the appearance of a ninth bladder. What appears to be part of another bladder on the right in the photograph, under the microscope seems to be a fragment of the bladder above it.

2 *A. hoffmeisterii* var., Slide D-46; H-142.2; V-123.0, Rowe coal, locality X. Fig. 2a shows positions of the 7 bladders and how the top corner is covered.

3 *A hoffmeisterii* var., Slide D-50a; H-140.6; V-127.0, Rowe coal, locality X. Fig. 3a shows positions of the 8 bladders at the corners, leaving the interradial margins uncovered near the mid-points.

4 *A hoffmeisterii* var., Slide D-52; H-135.5; V-113.4, Rowe coal, locality XI. Fig. 4a shows positions of the bladders.

5 *A. hoffmeisterii,* Slide D-52; H-150.7; V-114.9, Rowe coal, locality XI. Eight bladders.

6 *A. hoffmeisterii* new species, Slide D-57; H-147.0; V-128.0, Rowe coal, locality XI. Eleven bladders, counting the one on the proximal side near the lower right corner.

7 *A. hoffmeisterii* new species, Slide D-50a; H-147.9; V-108.4, Rowe coal, locality X. Fig. 7a shows positions of the 10 bladders and how they cover the two lower corners

8 *A. hoffmeisterii* new species, Slide D-52; H-143.9; V-115.9, Rowe coal, locality X. Dotted lines complete outlines of broken bladders.

PLATE III

(All spores magnified 508 diameters)

Figures

1 *Raistrickia* sp., Stigler coal, locality VIII, Slide D-27; H-149.2; V-120.4.

2 *Raistrickia* sp. Specimens from the Rowe coal, locality XI. Fig. 2: Slide D-59a; H-142.0; V-109.9.

3 *Raistrickia* sp. Specimen from the second coal below the Spaniard limestone, locality IX. Fig. 3: Slide D-33; H-136.0; V-120.0.

4 *Raistrickia* sp. Specimen from the Stigler coal, locality III. Slide C-42; H-138.5; V-119.1.

5 *Raistrickia* sp. Specimen from the McAlester coal, locality II. Slide C-37; H-142.7; V-109.8.

6 *Triquitrites protensus* (?) Kosanke, 1950. Specimen from the McAlester coal, locality II. Fig. 6: Slide C-32; H-142.2; V-113.3.

7 *T. pulvinatus* (?) Kosanke, 1950, Stigler coal, locality VIII, Slide D-22; H-137.8; V-109.0.

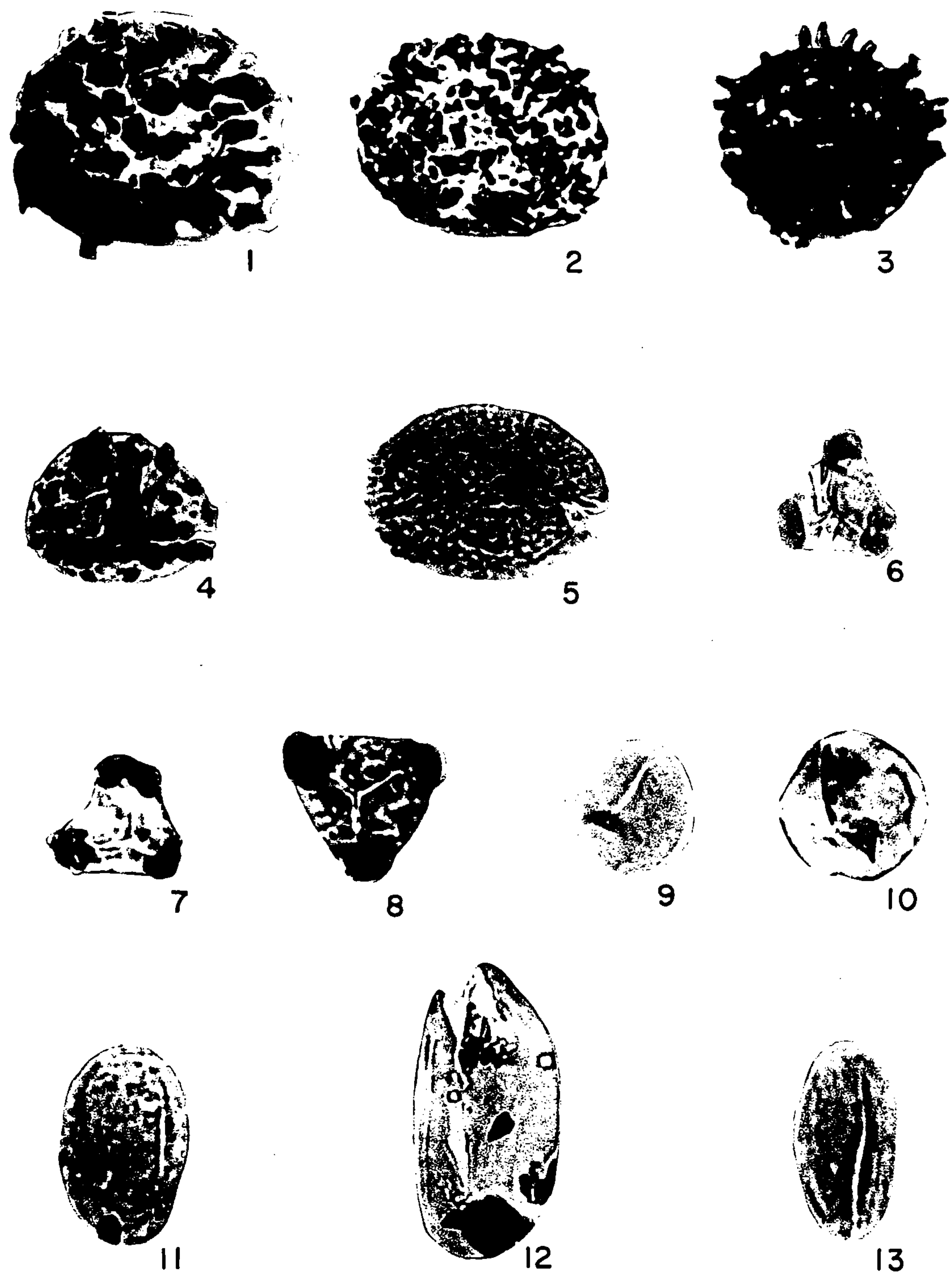
8 *Triquitrites* sp., Rowe coal, locality XI. Slide D-59a; H-148.3; V-123.0.

9-10 *Laevigato-sporites* n. sp. Wilson and Hoffmeister, Unpublished Manuscript, 1954. McAlester coal, locality II. Fig. 9; Slide C-32; H-134.5; V-111.5. Fig. 10: Slide D-67; H-140.0; V-118.4, coal at base of Spaniard limestone, locality XII.

11 *L. ovalis* Kosanke, 1950, Stigler coal, locality VIII, Slide D-27; H-146.4; V-119.9.

12 *L. desmoinensis* (Wilson and Coe, 1940) S., W., and B., 1944, comb nov., McAlester coal, locality Ic. Slide C-29; H-139.1; V-109.5.

13 *Laevigato-sporites desmoinensis* (Wilson and Coe) S., W., and B., 1944, comb. nov., McAlester coal, locality II, Slide C-37; H-144.2; V-112.6.


1
2
3
4
5
6
7
8
9
10
11
12
13

INDEX