Ancient Fires

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FIRE can produce, particularly by incomplete combustion, materials that can remain for an exceedingly long time. Thus, fossil charcoal can be used as an index of fires in the geological past. These early fires became a part of the earth's ecosystem shortly after the development of materials that would burn on its surface. The lightning discharge has bombarded the earth's surface even before the beginning of life on this planet. It is a mechanism that operates to maintain the electrical field that surrounds this planet. Certainly the bombardment of the earth's surface with an electrical discharge with a potential of more than 100 million volts and amperages of up to 20,000 has always had, and still has, a fire potential. The effect of such lightning discharges and their propensity for igniting fires has been adequately discussed in the past eleven Tall Timbers Fire Ecology Conferences by myself and others without belaboring the subject any further now.

Petrology, the science of coal, its formation, distribution, and characteristics does furnish an abundance of evidence that forest fires were an integral part of the earth's environment as far back at least as the Paleozoic Period. At that time extensive coal beds were formed in many parts of the world, particularly during the Carboniferous periods, some 400 million years ago. Petrology has shown that most coals or coal bearing strata contain a fossil charcoal called fusain and it is generally accepted that this was formed by natural fires, either by lightning or spontaneous combustion.

INTRODUCTION

Man has long known that the charring of wood would aid in its preservation when placed in or upon the ground. The charring of fence posts was a pioneering activity. In fact, this charring, though now mostly forgotten, is so recent that one of the neighbors of our farm, Birdsong, discussed this procedure with me in the middle or late 1930's. This was Albert Lee, of Grady County, Georgia and he recommended doing this for what he called "sap pine" fence posts.

In "Coal and Civilization" Jeffrey (1925) has an entire chapter titled "Fire as a preservative" because of the incidence of fusian or fossil charcoal in most coals and wrote:

> It has long been known that fire has a preservative action on wood. This agency is often invoked in the case of wood set in the ground. If the embedded region and the portion just above it, are exposed to superficial charring, the life of the structure is much prolonged. Charcoal is practically imperishable except as the result of combustion. Charcoals of the remotest geological ages reveal wood in a superb condition of preservation which is not approached by that found in the best petrified or mineralized material.

And later in the chapter he reiterates that belief:

> Plant remains which have once been exposed to the action of fire, are to all intents and purposes imperishable, except by the further action of fire itself.

FUSAIN — FOSSIL CHARCOAL

That fossil charcoal, such as fusain, is practically imperishable except by further action by fire is accepted by petrologists without much question.

Harris (1958) in *Forest Fire in the Mesozoic* has written that certain carbon materials that are found in coal can be interpreted, after a series of excellent and closely controlled experiments, as fossil charcoal produced by natural fires and that:

> This is no new idea; it was warmly put forward and warmly opposed a century ago, but of late interest has died because of lack of fresh evidence. Such fragments are often abundant and were once called mineral charcoal or mother of coal . . .

This material which is sometimes called "fossil charcoal" is now internationally called "fusain" or "fusinite" by petrologists. Williamson (1967) in *Coal Mining Geology* defines it as follows:

> Fusain is a common constituent of bright coal, occuring as thin silvery black bands most commonly a few millimeters thick. Occasionally it forms lenses up to about 8 in. thick. It is typically a very soft and friable, fine, soot-like powder forming that part of coal which is dirty to the touch. . . From its close physical and chemical similarity to wood charcoal, fusain is generally believed to have been formed in forest fires, possibly sparked off by lightning, which swept across the peat deposits.

At the American Conference on Coal Science, 1964, the following statement was made in relation to fossil charcoal or fusain that is found in coal formations.

> A commonly held view of the origin of some fusinites (fusain or fossil charcoal) is that pyrolysis occurred as a result of forest fires, perhaps ignited by lightning or meteorites. An alternative suggestion is that during the activity of thermophilic bacteria in decaying vegetable matter, spontaneous combustion starts from hot spots and carbonizes some of the material. (Austen, Ingram, Given, Binder, and Hill 1966).

In the resulting discussion after presentation of their paper Given made the following remarks:

> . . . In the first place I would point out that the fire has to sweep through the forest, not the bog. Secondly, modern research on combustion processes in forest fires makes it clear that, once ignited, a fire could perfectly well sweep through a semi-tropical forest in conditions of high humidity, and the humidity would actually contribute to the fierceness of the fire (the steam condenses at high altitudes and thus increases the "chimney draft" at the vortex of the fire). The difficulty is to visualize a suitable ignition process; lightning, the falling of meteorites, the ignition of marsh grass (spontaneously or by lightning), and the activities of thermophilic bacteria are possibilities.

Bergstrom (1931) in the "Spontaneous ignition of wood and the origin of Fusain" writes that:

> It would appear that the general opinion seems to be that fusain is formed from charcoal remaining after forest fires. Many facts would, however, appear to indicate that all fusain has not been formed in this way. In passing, it may be mentioned that it is possible that these forest fires may have been caused by spontaneous ignition occurring in heaps of vegetable matter . . .

The knowledge of fossil charcoal, and how it was formed has a background quite similar in differences of opinion in many ways comparable with the history of fire ecology. In fact, the impact of early foresters that all fires were destructive, that no good could come of them, and that they were literally man-caused permeated even the science of petrology. It is curious if not co-incidental that lightning fires although first proposed as the agent forming fusian as early as 1844 they were not challenged seriously until the early part of the 1900's when the science of forestry began its real impetus, with its total fire exclusion policies. Germany was the cradle of forestry and this philosophy that fires were a man made artifact was spread throughout the world. One of the leading German petrologists in the early 1920's was the most difficult to convince that there could be lightning caused forest fires.

However, today, it is generally recognized by petrologists that fusain, at least in part, was formed by lightning fires or forest fires that were ignited by spontaneous combustion, even as early as the Carboniferous coal bearing periods.

I would like to emphasize that fusian is fossil charcoal, not coal, but is found in association with coal of many kinds. It is the black soot-like material that rubs off on ones hands when coal is handled.

Ancient Forest Fires by Analogy

Another approach to these ancient fires is through analogy with present conditions. Many petrologists, (White 1913; Moore 1922; Jeffrey 1925; Thom Jr., 1929; Bergstrom 1932; Terres 1932; Stutzer and Noe 1940; Harris 1958; Krevelen 1961; Francis 1961; Williamson 1967; Mackowsky 1968; Teichmuller and Teichmuller 1968) have, in discussing the climate, topography and vegetation in the formation of coal beds, made reference to existing vegetations and conditions. Many of these circumstances to which they allude are directly related to what fire ecologists consider "fire environments;" i.e. Everglades, Okefenokee Swamp, Dismal Swamp, Southern Coastal Marshes, and southern pine forests for all of which there are abundant lightning fire data today. They also allude in many instances to the sequoia or "Big-Tree" forests which are also considered fire type forests. In fact, by coincidence, many of the papers being presented here at this conference will be discussing the kinds of vegetations and climatic conditions that petrologists refer to as necessary for past coal formations.

I have been fortunate to visit, study, and photograph many of the conditions to which the coal scientists refer to. Several of these have used pictures in their books of the areas mentioned. However, none of these apparently have any knowledge of fire ecology or of the studies in lightning caused fire. Thus I will quote their views as they are related to coal formation in these vegetation types and then attempt to add the lightning fire history and ecology as it might apply.

The following discussion of ancient fires will be by three main geological periods but not in chronological order. First will be considered the Mesozoic because of Harris's (1955) excellent experimental evidence on fusain in coal beds of that period in the British Isles; second the Paleozoic and thirdly the Tertiary.

FOREST FIRES IN THE MESOZOIC

Harris' previously referred to experiments were conducted with fusain and similar material from three coal bearing areas in the British Isles (E. Greenland, N. Yorkshire, and S. Wales) of Jurassic age. He mentions that "fusian is abundant, widespread and occurs in many horizons" particularly in the first two localities. From his experimental analysis he concluded that in several

> . . . respects the Greenland, Yorkshire and Welsh fusain specimens agree with recent charcoal from a burnt forest of the edge of a bonfire.

He compared fusain fragments "from an extinct conifer, *Cheirole pis muensteri* with those of a burnt *Pinus sylvestris* wood. . ." and found that:

> The recent charcoal looks like fusain; it has the same consistency, the same very high resistance to maceration and in the end reveals tracheid walls with beautifully clear pits. . .

He also compared fusain fragments of the fossil fern *Phlebopteris woodwardi* with a recently burnt *Pteridium* leaf; "this fern burns easily, but then goes out and the charred remnant does not readily glow but remains a black residue." I have seen a similar action after fires in southern longleaf pine (*Pinus palustris*) forests which contain an understory of *Pteridium* such as the "virgin" longleaf pine forest at Greenwood Plantation, Thomasville, Georgia. Under intense fires when the ferns are very dry the ash residue is white on the blackened burn and at times outlines the leaf in remarkable detail. I have also seen the same effect, black residue on burns under humid conditions, white ash under very dry conditions so that even twigs and small branches are outlined clearly, in Africa as well.

Harris in his experiments also compared fire cracks in the fossil material with that of wood from species of *Sequoia* and *Cedrus* which he burned and found them similar. He points out that the white ash is not always the end result of burning and that:

> However, this does not always happen in heath and forest fires, for plant fragments may be saved from complete combustion when they lie on the ground. Forest fires are of different grades, in some the heat is so intense and prolonged that even the soil is burnt. No small plant material remains, only the charred bases of trees, and when these break up the pieces show their origin from timber of large diameter. At the other extreme are fires limited to forest undergrowth or heath scrub, and these fires, which pass rapidly, sometimes do not even injure the trees. The soil surface is not burnt but slightly scorched in different patches. On such a burnt area the delicate plant organs remain on the ground as charcoal, in astonishingly perfect preservation. One time all the organs of *Pinus sylvestris* and leaves and flowers (even showing anthers) of Ericaceae. Still more minute things remain, carbonized moss leaves still determinable long after the fire and *Pteridium* with all their cells. Under the heat their volatile constituents distilled off, but their carbon residue was saved from becoming incandescent by the cool ground.

Harris then reconstructs the kind of fire that would have produced the results he had found in his Mesozoic fusain, a type of fire very familiar to fire ecologists:

> I suggest that the fire passed quickly through the *Cheirolepis* scrub; or it might be high forest with *Cheirolepis* saplings and litter. Twigs were burnt, no heavy timber, because the fire passed too quickly.

At the past eleven fire ecology conferences we have certainly seen and heard of many examples of such fires produced by lightning as well as by controlled burning. Harris was concerned because he had found charred beetle elytra remains in his Mesozoic fusain. Under the usual controlled fires here in the southeastern United States the remains of such beetle elytra are common as well as the chitinous remains of many other insects and invertebrates. At times some of these will retain their outside form in minute detail but consist entirely of ash; I have seen many examples of this with the remains of beetles, millipeds, snails, etc., in North America, Australia, and Africa.

FOREST FIRES IN THE PALEOZOIC

The Carboniferous was so named because of the extensive world wide coal deposits that were formed during that time. These coal deposits occur in North America, South America, Europe, Australia, and Africa. Francis (1961) in, "Coal; its formation and composition", shows an excellent map of this coal formation period particularly in relation to Gondwanaland. The coals of this period contain much fusain. That some carboniferous coal beds have extensive amounts of fusain is evident from the following:

> . . . In the United States two benches of the Pittsburg coal bed consist principally of fossil charcoal. These layers extend over 2,000 square miles.

Jeffrey (1925) in a discussion about fusain in a Paleozoic coal from Illinois writes:

> . . . This (specimen) represents the wood of the tree-like genus Cordaites, which was very abundant in the coal-forests of the Carboniferous. Such woods can easily be identified whenever fusain is abundant in the substance of the coal. A very large number of coals comply with this condition. Associated with the woods of Cordaites, which was a seed-bearing tree, allied to and probably ancestral to our living Conifers, are found, usually in abundance and well preserved, woody parts of tree-like Club mosses (Lepiodendrids and Sigillarians), and of the gigantic arboreal Horsetails (Calamites), the ancestors of our lowly Scouring rushes or Equieseta of today. If there were no other evidence

> available, the presence in coals of the woods of Cordaites, Lepidodendrids, and Calamites, would very clearly indicate the Paleozoic of such combustibles.
>
> . . . In many ancient plants such as the Lepidodendrids or tree-like Club mosses and the Calamites or arboreal Horsetails, the corky layers were well developed on the outside of the plant as a protective device. Corky tissues can often be recognized in coals and retain their organization, under the action of forces which have completely obliterated the structure of all remains of wood, except those which have been charred by fire.

Moore (1922) compares the conditions for developing coal beds with vegetation communities that are considered "fire types" in the south, points out that among the Lycopodiales:

> There are several living and many extinct genera in this group. *Lycopodium*, which is the best known, has been characterized by Coulter as possibly the best living representative of the earliest forms of vascular living plants.

It is interesting to note that a living representative of this group, our southern club moss (*Lycopodium alopecuroides*) is a very common inhabitant of several of our fire type communities in the deep south. At Greenwood Plantation, Thomasville, Georgia, it is found along with other possible "relics" of the past such as four species of ferns (*Osmunda regalis*, *O. cinnamonea*, *Lorinseria areolata*, *Pteridium aquilinum*) all of which have increased tremendously in the past 27 years by annual burning (under the direction of the writer) in a virgin long leaf pine (*Pinus palustris*) forest and slash pine (*P. elliotii*) in the wetter areas, all of which are apparently well adjusted to recurring fires. In fact, in the absence of fire they disappear rather quickly (in about 5 years) due in part to the direct effect of competition and shading of shrubs and young trees.

Another ancient group, the Cycadofilicales, likewise, has a fire enviroment representative in *Zamia floridana*, a very common inhabitant, where it has not been eradicated by human disturbance or by fire exclusion, of the southern coastal plain pine forests. It is shaded out by competing vegetations where not burned regularly. At the Everglades National Park it is becoming increasingly more abundant in the calcareous pine ridges since fire has been re-introduced.

FIG. 1. Severe fire going through dry cypress swamp, West of Naples, Fla.

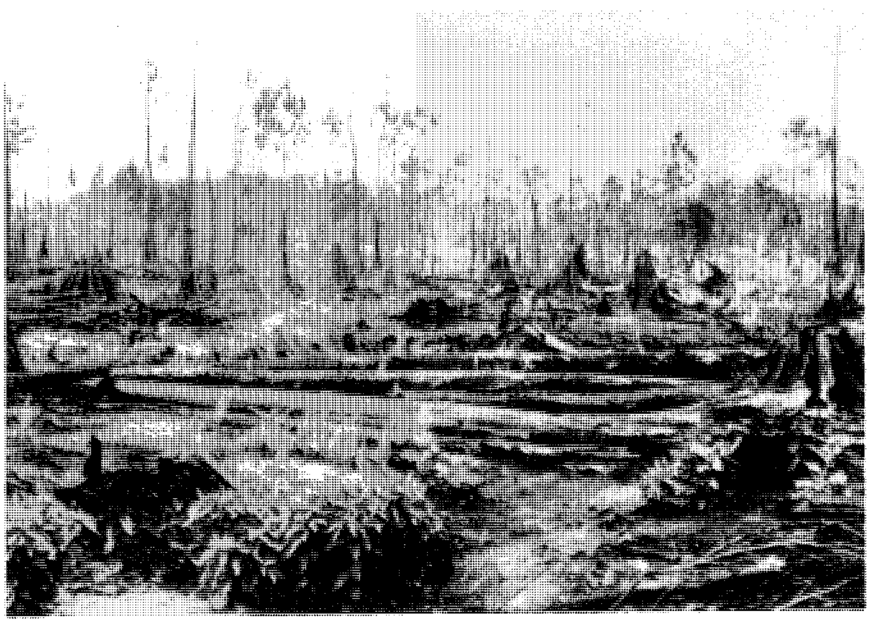

FIG. 2. After severe fire in dry cypress swamp, West of Naples, Fla.

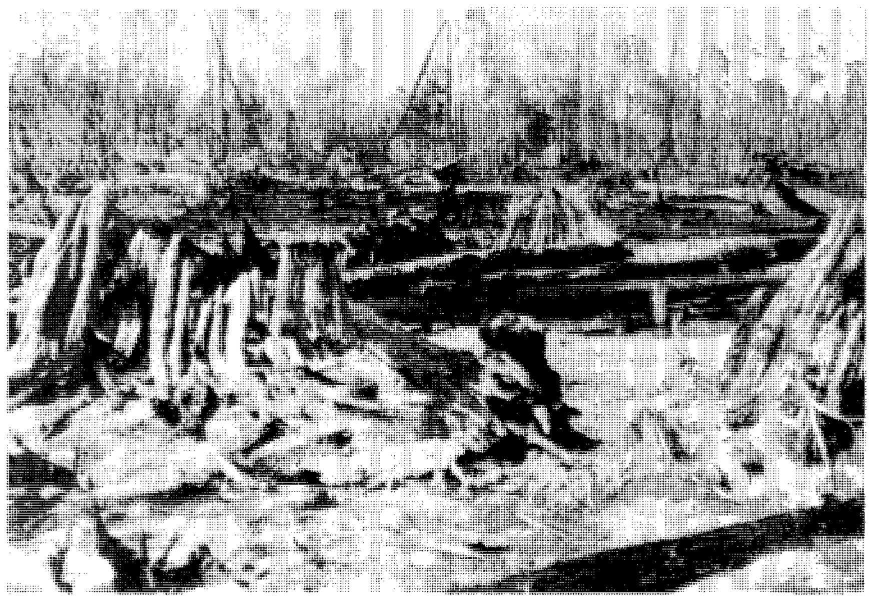

FIG. 3. After severe fire in dry cypress swamp, West of Naples, Fla.

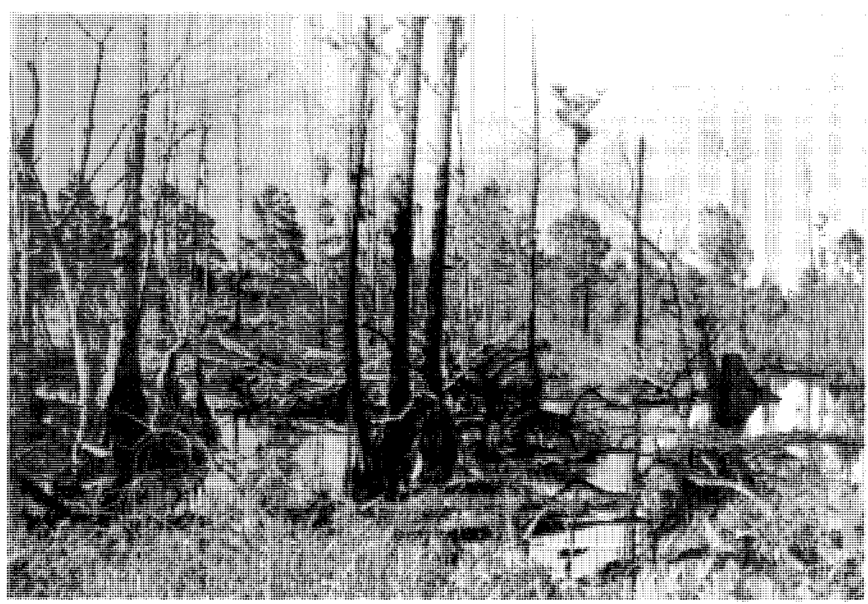

FIG. 4. Same swamp after rains.

Moore also discusses the beginning of the Conferales with their two main families, Taxaceae and Pinaceae, during the carboniferous, although they had earlier possible ancestors. In the Taxaceae are the Sequoia of which the present members are "fire-types" as well as the bald cypress (*Taxodium distichum*) which, although it lives in a wet enviroment, does have many "pre-adaptations" to fire. Fire is of frequent natural occurrence by lightning in such as the Okefenokee Swamp of Georgia and Florida and St. Marks Wildlife Refuge, Florida (Fig. 6). The Pinaceae as a group, have a remarkable collection of species that have natural fire relationships as shown by thick bark, serotinous cones, sprouting ability, need of mineral soil for germination, etc. The past Tall Timbers Fire Ecology Conference Proceedings are replete with discussions and bibliographies on all of these so no need to dwell on the matter here.

Krevelen (1961), likewise, has mentioned the probable conditions under which the Carboniferous coal beds were formed. These in many respects, are much like the southern swamp, marsh, pine forests, and coastal regions with a subtropical climate.

FIG. 5. Cypress swamp after a light ground fire, West of Naples, Fla.

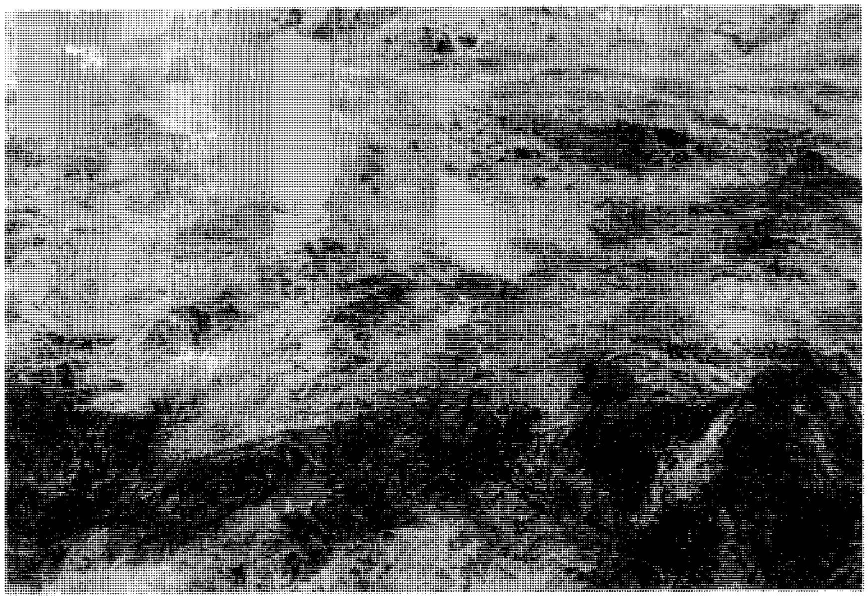

FIG. 6. Thin layer of grass ash and light charcoal after controlled grass fire over water, St. Marks Wildlife Refuge, Fla.

Many other plants of that period have relatives today under somewhat the same climatic conditions. Among these are many species of "tree ferns" which occur in both South Africa and in Australia (Darwin) and maintain themselves in typical fire enviroments. I have seen both of these subjected to recurring fires on both continents. Another such group of plants, *Pandanus* spp., is likewise subject to recurring fires near Darwin, Australia. In this example, I witnessed one of the most intense fires in a stand of large *Pandanus* spp. without apparent damage to the plant. Tropical and sub-tropical vegetations grow in many regions where they are subjected to some dry periods and these same regions are usually noted for their lightning and thunderstorm activity. However,:

> It has been pointed out, for instance, that the quantity in some bituminous coal beds is too large to be explained by forest fires, especially since comparatively small amounts of wood charcoal are produced in present-day forest fires. It is difficult to believe that such a thing happened, in view of the moist condition of

the Carboniferous forests, judging from the plant associations that grew there. Fires could not have spread rapidly in a swamp forest. . ." (Stutzer and Noe 1940).

The above statement is not correct for very large amounts of charcoal can be produced in extremely severe fires, particularly in swamps of Florida when they are dry. No matter how wet the swamps of the Carboniferous were, at times they could easily have dried out during relatively dry periods. The cypress (*Taxodium distichum*) and gum (*Nyssa sylvatica*) swamps of the coastal plain of the southeastern United States are full of water for periods of time but during droughts or just dry periods, they do dry up. Some areas of the Southeast, such as the before mentioned lakes of north Florida that contain cypress, will drain out by a natural siphon arrangement when the water table recedes to a certain level. This water table is not necessarily dependent upon the rainfall in the vicinity of the lakes and cypress strands.

I have examined cypress swamps near the Everglades that burned (Fig. 1) at a time when the peat and other vegetation was dry. In these swamps the tree root systems in the peat were burned out (Figs. 2, 3) allowing the trees to fall all over each other. These then were either consumed by fire, or in a great many cases, were charred by smouldering fire so that large amounts of charcoal as well as wood were left on the site. Filled later with water, the material was submerged (Fig. 4). In various parts of the swamps, many trees escaped such severe damage and in many instances, some of the swamps would appear to the unintiated in fire ecology as never to have burned at all. The cypress tree (Fig. 5), as well as the gum, *Nyssa* spp., are very resistant to fire and recover rather rapidly. Cypress, even where the top foliage has been decimated will throw out numerous adventitious buds and apparently completely recover. The bark of such swamp trees is generally quite thick and fire resistant in structure as well.

The lightning fires in the Okefenokee Swamp of south Georgia and north Florida have caused similar conditions but on a larger scale. After seeing these I certainly can believe that large quantities of charcoal can result from fires in what are normally considered very wet swamps. The climate of the earth has varied throughout all periods as regards to both moisture and temperature and so I can see no valid reason why fire was not a part of the Carboniferous Swamps when lightning was part of the Earth's atmosphere long before this period.

Mackowsky (1968) points out that:

> The formation of coalfields is bound up with well-known fixed conditions which include luxuriant plant growth on fertile soil, a moderate to tropical climate, a high watertable to ensure coverage of the plant material by water-laid sediments under oxygen-free conditions and an unevenly sinking basement that results in the development of coal seams alternating with other sediments. Such conditions are best fulfilled in the fore deeps of folded mountains.

The European Carboniferous coalfields were formed in this way. Such a condition could certainly result in rather extensive sedimentation due to fire. I recently examined the after-effects of a lightning wildfire (Carrizzo Fire) on the Apache Indian Reservation in Arizona (Fig. 7). This area, where over 71,000 acres were burned

FIG. 7. Accumulation of charcoal and debris after a severe thunderstorm following a lightning caused severe crown fire in ponderosa pine, "Carrizzo Burn", Apache Indian Reservation, Arizona, 1970.

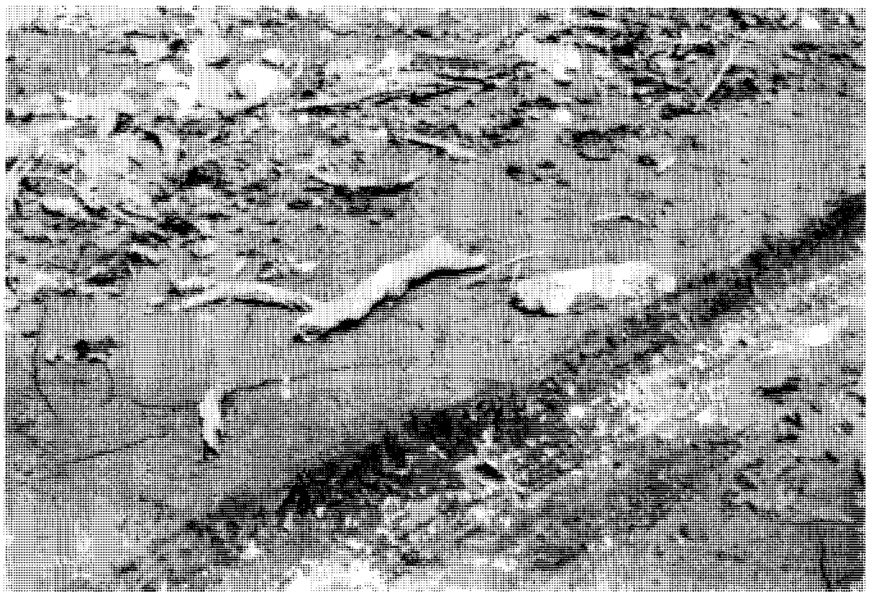

FIG. 8. Close-up view of Figure 7 showing depth of charcoal deposit.

over before the fire was brought under control, lies in rugged, mountainous country called the Mogollan Rim. After the fire, a heavy thunder shower occurred and an exceedingly large volume of black carbon-colored ash and charcoal mixed with some clay and sand detritous was washed down into the valleys. Here it accumulated so that this mixture of black material was as much as 8 to 12 inches deep and covered some areas rather uniformly to a depth of 4 to 5 inches. This was laid on top of vegetative litter, grass, etc., in a very dense layer.

TERTIARY PERIOD

In Francis (1961) we learn that Tertiary deposits of brown coal are replete with fusain and that:

> Thomson's (Thomson, 1950) work on brown coal in Germany shows that the stump layers consist of trees, including conifers, growing on relatively dry ground. These are not the typical coal forming trees, since they were frequently destroyed by fire,

> leaving bands of charcoal instead of coal. The true coal forming plants of the Rhine brown coals were the brush-wood type of angio-sperms and the reeds and grasses, growing under moist or water-logged conditions. The reeds and grasses often grew in open water, as in portions of the Everglades of Florida.

Thomson also visualized that one of the steps in the formation of Rhine brown coals was the "partial destruction of the forests growing under dry conditions by fire. . ." Francis (1961) points out that throughout the Tertiary with its many climatic changes, certain vegetations rapidly succeeded each other. There is a remarkable resemblance to plant species he and others list for this period with the successional pattern of like genera in the southeastern states created by different intensities, frequencies, and conditions of fire in this region.

> . . . the total duration of the formation of the Rhine brown coal deposits probably extended from the Eocene to the Pliocene, a period of some 50 million years. During this time, there were marked changes in climatic conditions, which are reflected in the plant types forming the successive layers in the deposits. For example, the lower layers, laid down whilst climatic conditions were warm or subtropical, contain such plants as the palm, *Liquidamber*, *Mohria* and *Lygodium*. The upper layers, laid down during temperature, (sic) conditions contain pines and firs, oak, alder, birch, chestnut and bog myrtle. (Francis 1961)

Teichmuller and Teichmuller (1968) in their presentation before the 13th Inter-university Geological Conference on "Coal and Coal-bearing Strata" pointed out that Germany is rich in brown coal deposits of Tertiary Age. In their "Cainozoic and Mesozoic Deposits in Germany" they reconstructed the vegetation and climate of those periods and made analogies between those and existing vegetations in Florida and adjoining states.

> The mega- and micro-botanical results, the evidence of coal petrological studies and comparative observations in present-day swamps, mainly of North America, where many of the plant genera found in the Rhenish brown coal are still living today, have allowed a reconstruction of different Miocene swamp types of the Cologne district. (Teichmuller and Teichmuller 1968).

This reconstruction is very pertinent to us at Tall Timbers

Research Station for most of the descriptions and photographs are of vegetation communities and associations that occur on the Station lands and adjoining regions. We have studied this complex of grass, marshes, swamps of Taxodium and Nyssa, along with adjoining conifer lands interspersed with various hardwood species of trees and shrubs. If these vegetations are comparable to the vegetation complexes and climate of the Tertiary then we, on the basis of our investigations here, can certainly understand the fire environment of the Tertiary. We have studied these vegetations, their flora and their fauna, and our preceding fire ecology conferences are replete with studies by other investigators throughout the Southeast in similar situations. Our region is a fire environment originally developed by lightning fires and today the area is known for its thunderstorm activity as well as the number of its lightning fires (Komarek 1964, 1966, 1967, 1971). I have just recently realized that in studying the lightning fires, thunderstorm activity, and their relation to fire environments in the southeastern United States, that I have, also, in an analogous manner, been investigating the fire environments of the Tertiary as reflected in the brown coal deposits of the world.

Teichmuller and Teichmuller base their reconstruction on certain peat forming situations such as the Everglades, with its large area of sawgrass (*Mariscus jamaicensis*) and other sedges and marsh which without fire is invaded by willow (*Salex* spp.) and other woody or shrubby growths; with the Cypress swamps such as the Okefenokee Swamp of Georgia, a large portion of which was burned out by lightning fires in 1954–55. They compare our "bay-tree hammocks", "bayheads", or hardwood ravines of *Magnolia virginiana* and *Persea borbonia* with the *Myricaceae-Cyrillaceae* angiosperm forest swamp "distinguished by Thomson as another kind of forest swamp of the Rhenish brown coal." They likewise point out that some of these types are characterized by an "abundance of humic gels and by layers of fusain (Teichmuller 1950)."

The processes they describe for coal formation are quite evident around Tall Timbers Research Station, for on the station grounds we have a cypress swamp (*Taxodium distichum* and *T. Distichum* var. *nutans*), a black gum swamp (*Nyssa sylvatica* and other species), "branches" or small valleys along drainage ways contain bays (*Mag-*

nolia glauca and *Persea floridana*), along the drier parts and edges are found *Liquidamber*, *Myrica* and other hardwood shrubs. The ridges are covered with a conifer forest of several species of pine such as the longleaf (*Pinus palustris*) which has been termed the "Forest that Fire Made," (Greene 1939) because of its fire requirements, slash pine (*Pinus elliotii*), short leaf pine (*Pinus echinata*) which will sprout profusely from basal buds when the main stem is killed by fire, pond pine (*Pinus serotina*) with fire adapted serotinous cones. The latter species grows in wet pond or marshy areas that contain such highly inflammable and fire adapted plants as the *Arundarias* commonly called "cane-breaks." In south Florida, around the Everglades and other areas, the pine ridges consist of southern slash pine (*Pinus elliotti* var. *densa*) are even more fire resistant and adjusted than longleaf pine. These plant communities are associations and are certainly some of the most fire tolerant and fire habitats anywhere.

Tall Timbers Research Station is situated on Lake Iamonia, and nearby are other such shallow lakes as Lake Miccosukee and Lake Jackson. Before dykes were built these lakes would formerly go dry more or less periodically over a period of years when fire would sweep over them. Marshes and swamps will burn over even though they are filled with water if enough dead grass, sedge, or other debris accumulates. The dead material burns and sometimes ignition temperatures are raised high enough for even the green vegetation to burn, with intense heat, enough to kill back invading shrubs and trees to the water line. Burning in the Everglades, in the marshes of the Gulf of Mexico coast, and shallow lakes, is common by lightning as well as by man. The fire can sweep over the water, burning out the vegetation above the water level and depositing the ash on the water. The wildlife refuges from the Delta Wildlife Refuge of Canada (Ward 1968) to the St. Marks Refuge (Givens 1962) on the Gulf coast of Florida use controlled burning as a regular management tool for the maintenance of marsh vegetations and to prohibit the invasion of woody species of plants. The Everglades National Park has frequent lightning fires in the "glades." They likewise use controlled burning to maintain the grass or sedge vegetations.

Even during drought years it is surprising how little of the accumulations of peat burn out. The peat holds enough moisture so that fire simply sweeps above it leaving a layer of ash residue and charcoal on top. What apparently has not been recognized by petrologists interested in the formation of coal, is that most such plant communities such as marshes, etc. would be invaded by shrubs and trees. The grasses and sedges simply cannot tolerate excessive shading and without some such agency as fire they soon would cease to exist. The Everglades region and adjoining areas of south Florida have had one of the longest and most intensive droughts on record in 1970–71 and a very large portion of the region was burned over. Investigation by my wife and me have failed to see where any large accumulations of peat were burned out in spite of the drainage canals and drought. These wildfires simply swept over the peat accumulations and only in rare instances were we able to find where the fire burned down into the accumulations. However, this can happen. I saw Delevan Marsh in southern Wisconsin burned out so completely, (about 1929) so that the layers of ash were over 1 and 2 feet deep. The marsh had, however, been intensely drained and I do not believe such fire effects occurred in nature except in very rare instances.

It is interesting to note that in the brown coals of Victoria, Australia (Francis 1961) such a fire-adapted genus as Banksia is well represented. Banksia, in Australia today, have serotinous "cones" and banksia communities regenerate profusely after fires.

Thus, if the brown coal regions of the Tertiary are analogous to the vegetations of the southeastern part of the United States and Australia, we can answer Harris' remarks in relation to fire in the Tertiary affirmatively. When the Tertiary coals were formed fire must have been widespread from natural causes.

PERIODICITY IN COAL FORMATION

My investigative excursion into petrology or the science of coal formation has not only been of great interest but also has created some speculation on my part on the relationship of fires to coal formation. Many authors have stressed the rather rhythmic patterns of coal formation and banding with minerals, sediments, and *fusain or fossil charcoal.* Francis (1961) writes:

> . . . a rhythmic or cyclic processes of subsidence and coal forma-

tion occurs in brown coals that is similar to that of bituminous coals . . .

The banding of fusain in many coal fields apparently also show a rhythmic or cyclic process of deposition. Could this be related to the "rhythmic or cyclic" pattern of lightning fires such as in western United States where enough record of such fires have been adequately kept on U.S. National Forests? These show a possible rythmic pattern. The thunderstorm is the generating process for the lightning strike and some meteorological conditions appear to show periods of re-occurrence over long periods of time. (Komarek 1967).

NATURAL FIRES AND COAL FORMATION

Fossil charcoal is found in anthracite, bituminous and brown coals, some of which is in the form of "coal dust." "The proportion of fusain in most coals is small, generally less than 3%, though occasionally bands or pockets of large dimensions occur that consist almost entirely of fusain." (Francis 1961). The fact, however, is that it occurs in most coals and some of it is "typically a very soft and friable, fine, soot-like powder forming that part of coal which is dirty to the touch." (Williamson 1967). I cannot help but wonder if this fossil charcoal, forest fires, and coal formation have a relationship that has not been recognized. With any fire of organic material, not only can charcoal be produced, but certain minerals such as calcium, potash, phosphorus, etc., are released in mineral and soluble form. Just above the flame are particulates (fine particles) of charcoal which settle back to the surface of the ground. Studies in the air pollution qualities of wood smoke have brought out the fact that the more moisture the burning material contains, the more particulates that will be generated. In "cool fires", that is, those that occur under wet or damp conditions, these settle to the ground. Could this be the "dirty to the touch" part of coal? Besides the charcoal, particulates, and the release of soluble minerals that might have an effect on coal formation, we also have the ability of charcoal to absorb gases and fluids to a remarkable degree. As is evident from reading petrological literature, the processes inherent in coal formation are not too well understood, although there are many theories and ideas. The fact that coal is formed under rather damp or wet conditions (everyone appears to agree on this) would lead to those kind of fires that produce the most charcoal, and the least ash, as well as most fine charcoal in the form of the dust-like particulates which apparently are even more absorbent than pieces of charcoal. All of this, of course, is speculation on my part but the constant and recurring fact of fossil charcoal (which means to me, fire) in connection with the formation processes of coal would appear to show some undetermined relationship.

SUMMARY

I have reviewed, but briefly, the extremely abundant literature on coal formation with reference to the occurrence, development, and characteristics of fossil charcoal, "fusain." The findings in petrology, the science of coal formation and development, show that fusain, a fossil charcoal, is similar, if not identical, with charcoal produced by present forest fires. The petrologists are in agreement, with very few exceptions, that fusain was produced by natural (lightning and spontaneous combustion) fires and that the same coal forming processes and principles that occurred in the past geological ages continue to operate today.

The petrologists are apparently all in agreement that many, if not most, of the coal deposits from the Carboniferous through the Tertiary were formed under situations quite similar to those that occur in the southeastern states today. They have, by analogy, compared present day vegetation complexes and situations with those that have occurred in past coal forming periods. Without exception, the conditions and vegetations that they have used analogously in the formation of coal and fusain are situations and vegetations that we consider as "fire environments" and "fire types" in the South today.

The evidence in the science of coal formation, petrology, abundantly proves that natural fires have been present throughout the coal forming periods, from the Carboniferous to the present.

I have speculated that forest fires and their consequent "debris" such as fossil charcoal, ash, etc. may in themselves be an important, and even perhaps a necessary ingredient in coal formation.

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