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ENVIRONMENTAL ANALYSIS OF SANDSTONES AND QUARTZITES FROM THE TALLAHATTA FORMATION, NEAR MERIDIAN, MISSISSIPPI

William F. Tanner
Regents Professor, Geology Department
Florida State University
Tallahassee, Fla. 32306-3026

ABSTRACT

The Tallahatta Formation, near Meridian, Mississippi, contains both muddy sandstones (with significant silt and clay content, but no silica cement) and quartzites (quartzose sandstones having silica cement), in close stratigraphic and geographic proximity. This paper presents granulometric suite data from both kinds of rock, to see if the use of hydrofluoric acid (HF), to remove silica cement, modified the grain size distribution in a significant way. The environment of deposition, deduced from the grain-size parameters, was in the zone of surf-and-swash action, under low-to-moderate energy waves, plus settling from water, coupled with some wind work. This is a common combination on sub-aerial beaches. The resulting data are not sufficient to prove that HF treatment did not modify grain diameters, but the evidence (now available) supports this proposition.

INTRODUCTION

This study of part of the Tallahatta Formation was undertaken in the hope of determining the validity of granulometric analyses of quartzites (silica-cemented quartz sandstones) that have been treated with hydrofluoric acid to remove the silica cement. The Tallahatta Formation, in the vicinity of Meridian, Mississippi, contains both argillaceous sandstones (mudstones), and quartzites (quartzose sandstones with silica cement). Each represents a low-to-moderate-energy near-shore and beach environment plus settling from water, coupled with a significant component of wind work. They differ primarily in presence or absence of an important clay fraction. They also differ slightly in certain granulometric parameters. Ideally, the two kinds of sandstones might be expected to yield essentially identical grain-size results.

It is possible that the small differences between the two reflect the fact that the quartzites were disaggregated by using hydrofluoric acid. On the other hand, previous work indicates that the effect of this acid, on framework grains, should be slight, and differences among the samples might be environmental in nature. Until this uncertainty can be resolved, one does not know whether or not conditions of deposition oscillated between two slightly different environments. Clay content appears to have fluctuated in response to wave energy level changes, which may have been controlled by small sea level changes, but it must not be inferred that clay-content differences are necessarily mimicked by various grain-size parameters.

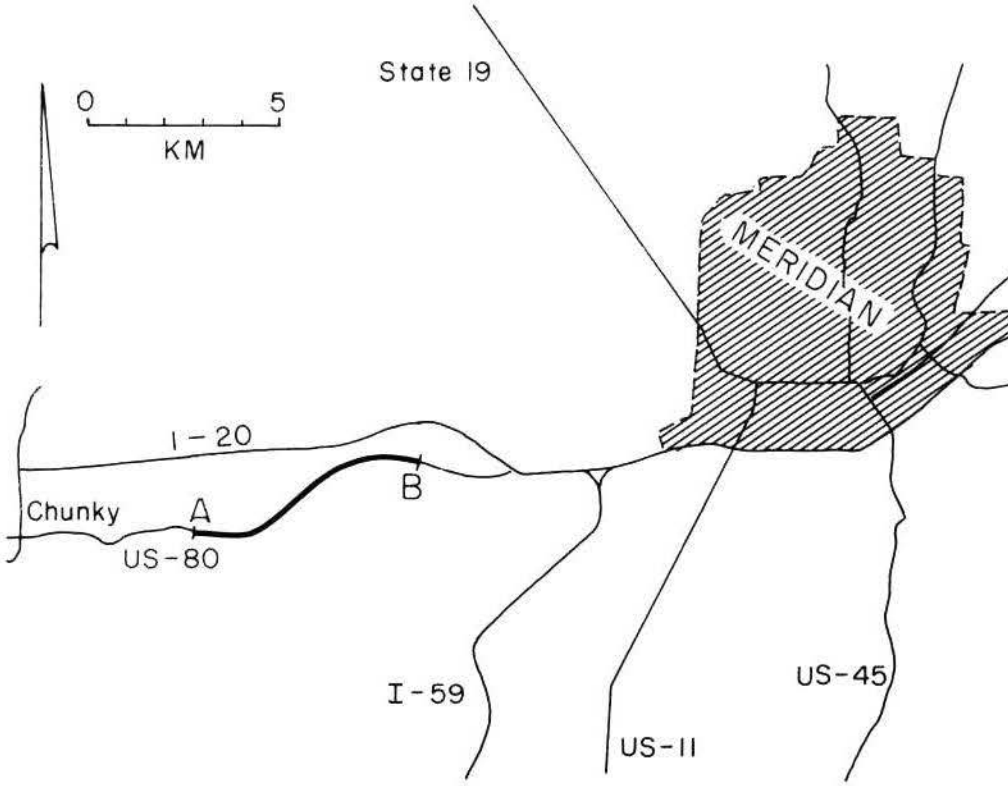

Figure 1. Map of the Meridian, Mississippi, area, showing where samples were collected: along U. S. Highway 80, between A and B, east of the village of Chunky.

METHODS

The Tallahatta Formation, of Eocene age, contains clay, argillaceous sandstones (mudstones) and quartzites (silica-cemented quartzose sandstones; cf. McGahey et al., 1992). This low-dip unit was inspected in the field at a number of localities south and west of Meridian, Mississippi, and samples were collected for granulometric work at several exposures along U. S. Highway 80, from about 12 km west of the center of Meridian (straight-line map distance) to about 17 km west of the city.

Samples included both quartzites and argillaceous quartzose sandstones. No truly clean, friable quartz sandstones were seen in the course of field work.

The purpose of this work was to compare the granulometries of more-or-less equivalent sandstones and quartzites. All of the samples discussed here came from the one formation, in a very small geographic area, and may represent a single environment, with only slight changes of depositional conditions.

Six samples of argillaceous sandstone were selected for processing. For these samples, the sand fraction, and the "finer than sand" fraction, were separated by wet sieving. The sand was dried, weighed and then shaken mechanically for 30 minutes in a stack of quarter-phi sieves (Socci and Tanner, 1980). The sand portion typically weighed 30-45 grams, and the fines, 8-11 grams. After sieving, each size fraction was weighed to 0.0001 grams, and the raw weights from the sample were treated in the GRAN-7 computer program, which produces a tabulation of data, the first six moment measures, various other parameters, a histogram, and a probability plot. Then the weight of the fines was added, numerically, to the pan fraction data in the array of quarter-phi results, and the combined sample was also treated in the GRAN-7 program. This produced two sets of results for argillaceous sandstones: one composed of sand, silt and clay, and one with sand only. The latter had been washed in the lab, and can be described as clean sand.

The average silt-and-clay component was 23.31%, which is about what one expects in sediments in transit in large alluvial rivers, or in lakes, estuaries or low-energy near-shore areas where such rivers debouch. It is not representative of mature beaches, sand dunes, or the clean sand of certain rivers. Therefore the clay-and-silt content appears to indicate proximity to an alluvial river source.

Various parameters from the GRAN-7 analysis were employed for more elaborate testing, using the SUITES computer program. One of the products from the latter is a pair of tests for homogeneity within the suite: that is, do the data indicate that two suites, of different kinds, have been combined in the field work, inadvertently? This analysis shows that field and lab work did indeed produce consistent results, and that there has been no mixing of different suites, but it cannot absolutely exclude the possibility of a systematic field error of some kind (at present not known). If this were a major problem, one could explore the possibility of some small systematic error by re-sampling the Tallahatta Formation in the same general area.

Six samples of quartzite were also selected for analysis. These were treated with dilute hydrofluoric acid until disaggregated, then washed, dried, sieved, and weighed, and the weights were processed in the GRAN-7 program. It was thought that the HF would attack the cement preferentially (Folk, 1989), and leave loose, essentially unaltered, quartz sand grains for further analysis. Orhan (1989) showed that the presence of pervasive silica cement indicates an initial absence of clay on the quartz grain surfaces or in the interstices. More recently Ehrenberg (1993) reported, from a totally different area, that clay (in his study, chlorite) inhibits silica cementation. Apparently a clay lattice does not provide a good template for initiating crystallization of proto-cement whiskers of SiO_2.

Therefore we contrast two rock types: argillaceous quartzose sandstones (with 20-25% silt-and-clay), and more-or-less clean quartzose sandstones (with silica cement; hence quartzites). The significance of this comparison is very important. In the first case, deposition either took place in a protected environment, or involved such a large proportion of the clay fraction that the latter could not be eliminated or even reduced greatly, at or close to the depositional site. In the second case, deposition involved only clean quartz sand, from which the fines (assuming the same source) had been removed prior to deposition.

This means that there are now three data sets: one for argillaceous sand, one for artificially-cleaned sand, and one for quartzite (after treatment with HF). It is thought that silica-rich ground water later deposited cement on clean quartz grain surfaces, but did not affect clay-coated grains (Orhan, 1989; Ehrenberg, 1993). The argillaceous sandstone furnishes baseline data, because it has been subjected to a minimum of laboratory treatment.

RESULTS

Granulometric analysis and environmental interpretation for sands is best carried out on sample suites, where the numerical results are less erratic, less scattered and more nearly diagnostic, than are numbers from individual samples (Tanner, 1991a, 1991b). That is, there is a great deal of hydrodynamic (environmental) information in the sample suite, and this information cannot be obtained from a single sample, or by looking individually at single samples in a set. Statistically, this means that one should evaluate (among other things) measures of variability for the suite of samples, such as the standard deviation of the mean diameter, and the standard deviation of the kurtosis. As will be discussed below, suite statistics indicate that the Tallahatta sandstones represent a low-energy beach or near-shore environment.

The mean diameter for the argillaceous sandstones (mudstones) was 2.91 phi (0.133 mm, which is not quite as small as 1/8 mm). For the washed sandstones, it was 2.377 phi (0.193 mm), and for the quartzites, 2.346 phi (0.197 mm); these last two should be compared. The mean diameters are small, in comparison with many modern beach and near-shore sands, but not as fine as the compact sand at Daytona Beach, Florida (2.48 phi; about 0.18 mm). The washed sands and the quartzites appear to have the same diameters, but this close similarity does not extend to all the other available parameters. The mudstone has a finer mean diameter than the other two data sets because it contains a significant fraction of clay-and-silt, but this finer diameter can not apply to the sand fraction if the latter is taken by itself.

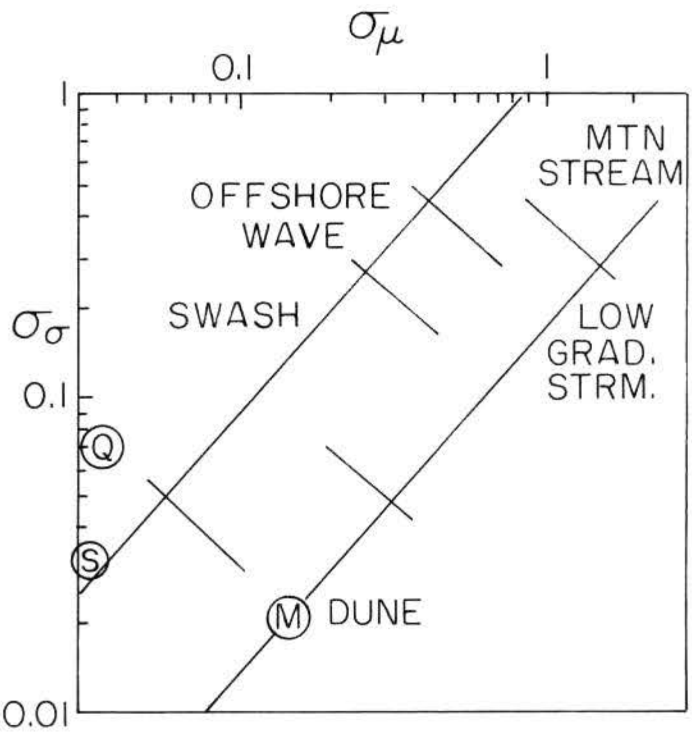

Figure 2. Variability diagram (standard deviation of standard deviations, vs standard deviation of mean diameters). Key: M = argillaceous sandstone (mudstone), S = artificially washed sandstone, Q = quartzite. Two of these three sample suites fit in the area marked "Swash or dune," and one of them (S = washed sand) indicates "Dune." Interpretation: beach and eolian, which is a common combination.

Further discussion of the quartzites will be deferred until a later section, because one does not know for sure to what extent the hydrofluoric acid may have attacked the separate grains. Hypothetically there should be no uncertainty: reduction of diameter, rather than smoothing of corners, is the critical question. Acid attack on corners or smaller projections

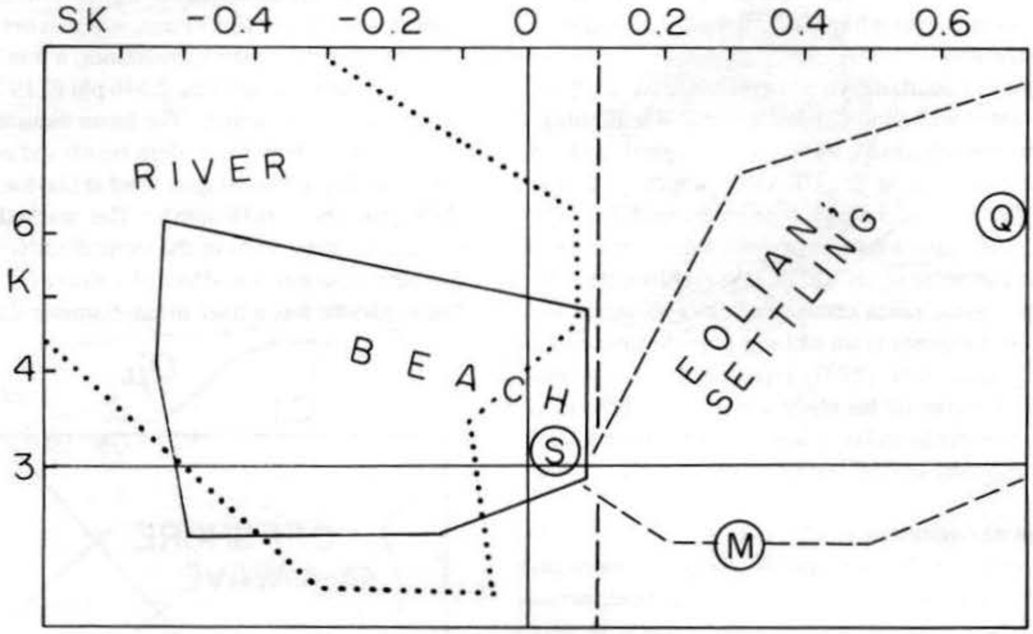

Figure 3. Kurtosis vs skewness. Key, as in Fig. 2. The washed sand indicates a beach, the other two suites indicate settling from water, or wind work. Interpretation: beach, settling from water, eolian.

would appear to do essentially nothing to the grain diameter, but in the case of the Tallahatta Formation, at least, this proposition has not been proven. The results of Schultz (1980) and Folk (1989) indicate that not even corners of framework grains in simple quartzites are attacked in any significant way by hydrofluoric acid. Quartzites in which there has been deformation of original grain shapes, such as by pressure solution or by shearing, pose a different kind of problem, but one that is not present in the low-dip Tallahatta Formation exposures, where structural deformation has been minimal.

Environments: Clean Sand

The clean sand (clay removed in the lab by washing), using suite-statistics procedures, produced the following results (hydrodynamic logic is discussed elsewhere: Tanner, 1991a, 1991b):

i. Variances of means and of standard deviations of the tail of fines (weight percent, 4 phi and finer): mature beach or dune.

ii. Skewness vs kurtosis of diameters: beach or settling (shallow water).

iii. Variances of diameters and of standard deviations (total sample): beach or dune.

iv. Relative dispersions of mean diameters and of standard deviations: dune.

v. Kurtosis vs sixth moment measure: eolian.

vi. Mean of kurtosis vs standard deviation of kurtosis: deep sea, or moderate-to-high energy beach. The first of these can be discarded.

vii. Kurtosis vs standard deviation: settling from shallow water, or tidal flat.

viii. Mean vs standard deviation: settling from water.

These results were obtained after washing in the laboratory; that is, the clay-and-silt fraction is not represented.

Environments: With Clay

The argillaceous sand gave, as was expected, slightly different results:

i. Tail of fines: settling in a closed basin, or where energy levels were too low to winnow the sediment very much.

ii. Skewness, kurtosis: settling in shallow water.

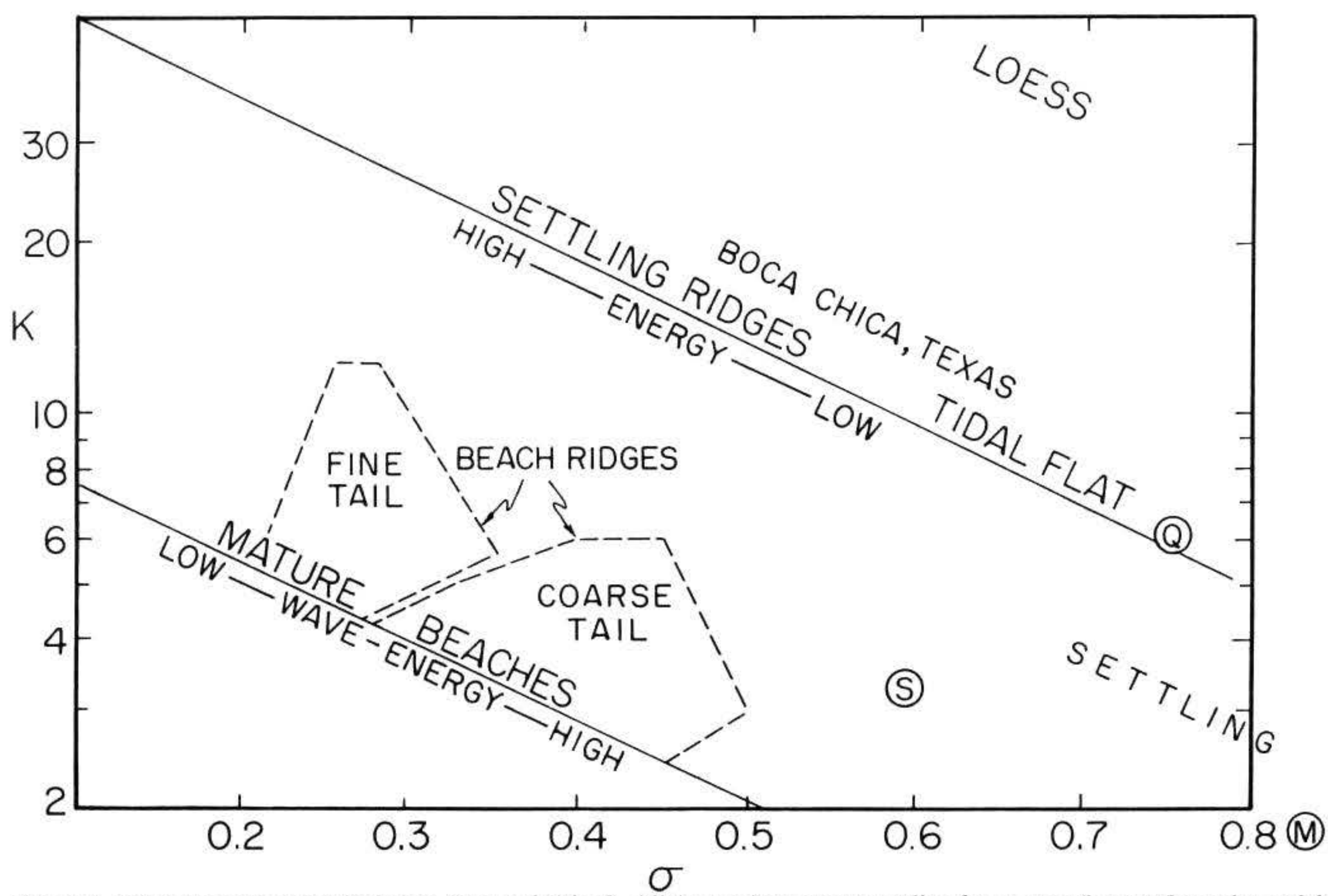

Figure 4. Kurtosis vs standard deviation. Key, as in Fig. 2. All three suites suggest settling from water (but not from air), and the washed sands show some evidence for swash work as well. Interpretation: beach, settling from water, tidal flat.

iii. Variability of mean and of standard deviation: beach or dune.

iv. Relative dispersions of mean and of standard deviation: dune.

v. Kurtosis, sixth moment measure: eolian.

vi. Mean and standard deviation of kurtosis: settling in deep water (relative to waves, which may have been small).

vii. Kurtosis vs standard deviation: settling from shallow water, or tidal flat.

viii. Mean vs standard deviation: settling from water.

These two lists show many items that are roughly evenly distributed among beach, dune (or eolian), and settling from water. The argillaceous sand shows much more evidence for settling from water than does the clean sand, but both indicate this origin. High clay content of the argillaceous sand necessarily shows settling from water, rather than traction (bed load) transport of the clay, but the clean (washed) sand also has characteristics due to settling from water.

The probability plots of the clean-sand size distributions have two interesting characteristics: (a) each is faintly bimodal, which suggests a mixture of two sources or two transport mechanisms (perhaps incomplete reworking of sediment from one agency, by a second agency), and (b) some of them have the distinctive kink known as the "surf break," which appears to be diagnostic of the beach and surf-zone environment, generally with low-to-moderate wave energy (Tanner, 1966, 1991a).

It should be kept in mind that "beach" granulometric characteristics may be acquired by sediments fairly far out on the shelf, as well as on the sub-aerial beach, for at least two reasons: (a) storm waves break farther out on the shelf, and produce solitary wave transport (much like the swash) in water depths where fair-weather waves may not be effective, and (b) there are small (up to 4-5 m) and alternating changes in sea level which may be hard to identify in other ways, but which have the effect of subjecting deeper-water sand to fair-weather wave and surf action, or of temporarily removing shoaler-water sand from the effects of wave breaking (Tanner, 1992, 1993).

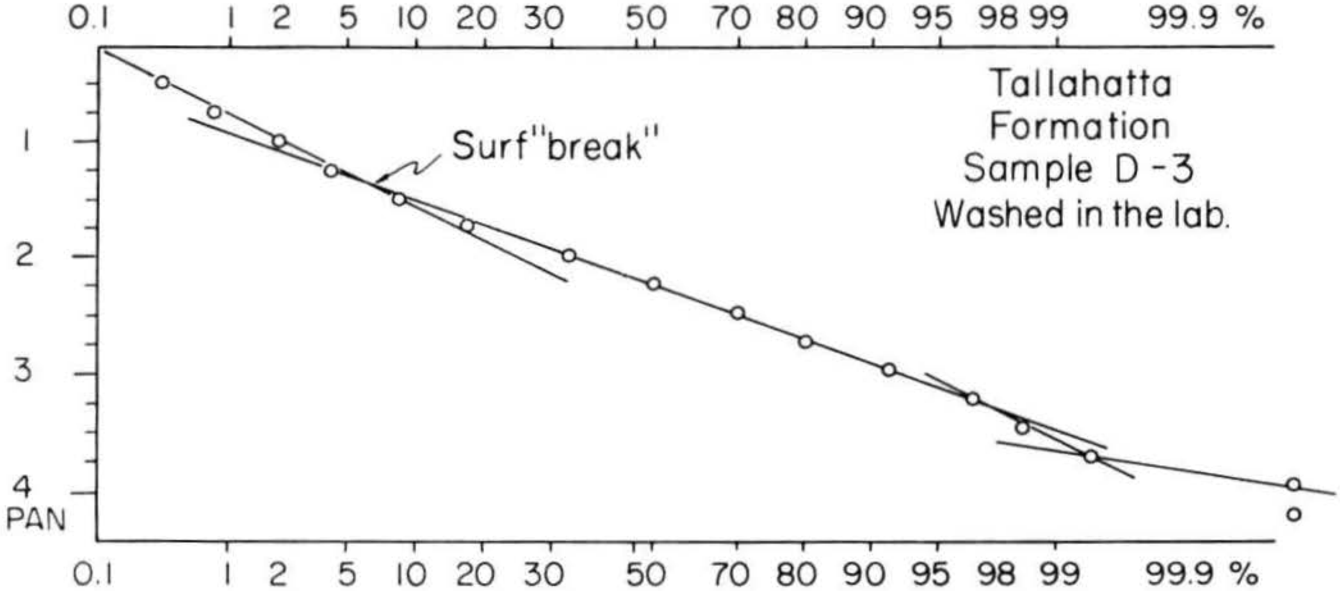

Figure 5. Probability plot for Sample D-3, an argillaceous sandstone, washed in the lab to remove silt and clay. Note the surf "break," which is a positive indicator of the surf-and-swash zone, having low-to-moderate wave energy. This kink, or "break," is located at about 1.30 phi (0.40 mm).

It should be kept in mind also that shallow-to-intermediate-depth near-shore sands commonly show (in the suite sense) evidence of both wave work and settling from water (the latter, during the waning phases of storms, or as evidence that waves were small most, but not all, of the time). Therefore "beach," "low energy" and "settling" indicators, taken together, identify a specific environment of deposition.

The evidence for wind work does not counter any of the foregoing: swash and wind influence are commonly combined on sub-aerial beaches. There is no evidence, in these data from the Tallahatta Formation, for non-coastal eolian activity (continental interior dune field).

INTERPRETATION

Do the results for the clean (washed) sand match any well-known environments of deposition? Yes, they do. One should infer a near-shore (and/or shallow shelf) environment, with episodes of settling, and also with non-trivial episodes of exposure to the air (wind work). The wave energy level (wave energy density) was low-to-moderate, rather than high. The sand-silt-clay results do not change the inferences any; they merely add the proviso that there must have been a good source of fine sizes (silt and clay), not too far away. "Not too far away" has to do with the local wave energy density (wave energy level), versus the volume-delivery-rate of fines introduced into the area. If the wave energy was high, then the source of fines must have been both large and in the immediate vicinity. If the wave energy was low, then the source of fines could have been much smaller, and/or much farther away. In the absence of evidence for well-developed channels, a large nearby source is not indicated, therefore the second option (low wave energy) can be adopted. Some of the granulometric parameters, used here, also suggest low-to-moderate wave energy density.

The tidal-flat item in the lists above, much like the dune indications, supports the idea of exposure to the air, and these two kinds of results limit the possible general water depth. A broad estimate of depth of water would be in the range of some centimeters to a few meters, plus considerable variability from time to time. (For a discussion of tidal-flat-plus-wind-work, see Tanner and Demirpolat, 1988.) The presence of a few marine fossils in the Tallahatta is consonant with the interpretation given here.

Quartzites

Results from the quartzites are disappointing, in that they do not indicate precisely the same environment as the argillaceous sands. But they appear to represent a "settling" and near-shore environment, which is roughly what the sandstones showed. This is encouraging in the sense that all three sets of numbers should agree in a general way. However, the uncertainties are, unfortunately, still great.

It is not possible to say from the granulometric work that the quartzites represent exactly the same environment as the argillaceous sandstones (mudstones). The primary difference, of course, is the presence or absence of clay. The secondary difference is that the quartzites show a small but significant fraction of fines (apparently silt, because clay inhibits the development of silica cement): 2.5 to 4.5%. This is enough to change the "beach" indication, in some of the tests, to "set-

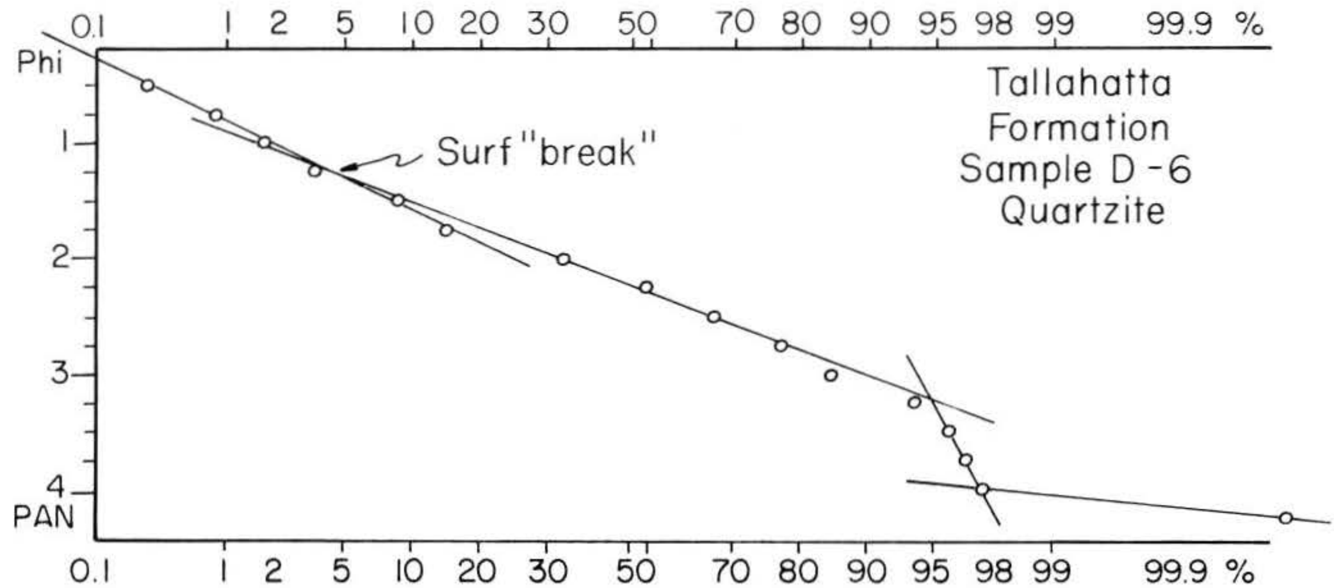

Figure 6. Probability plot for Sample D-6, a quartzite, after treatment with hydrofluoric acid. Note the surf "break" at about 1.25 phi (0.42 mm). It identifies low-to-moderate energy surf-and-swash. Compare with Figure 5, where the surf "break" is almost identical.

tling" or "eolian."

Therefore a fourth analysis was run; in this case, data from the acid-treated sandstones were analyzed after the pan-fraction (2.5 to 4.5%) had been set arbitrarily to zero. (This is a procedure which has been used previously on many occasions, commonly with valuable outcome: it focuses attention on the sand fraction.) The result is an almost perfectly Gaussian grain size distribution for each sample; this would be extraordinarily hard to get by direct artificial manipulation of the numbers, which in turn suggests that the procedure is a useful one. In the usual course of events, one might expect low standard deviation values to go along with the Gaussian distribution (e.g., r = 0.25 to 0.45), but the Tallahatta quartzites showed r = 0.6, which means less-than-excellent sorting. A tourist-type beach is not indicated.

The kurtosis and the sixth moment measure, for this fourth set of numbers, are almost identical with what was obtained for the washed (originally argillaceous) sand. These two parameters are especially sensitive to changes in the extreme tails, rather than in the middle part of the distribution. Their near-identity with the sand component of the argillaceous samples is encouraging, and provides a small amount of hope that perhaps the two do indeed represent the same depositional conditions, or nearly so. However, more work must be done before this proposition can be demonstrated.

Uncertainties

At this point in the study, we are unable to distinguish, in a completely satisfactory way, among several possibilities:

1. The environment of deposition for the quartzites WAS indeed different, at least in detail.

2. The HF treatment produced the apparent differences, and the environments were actually identical.

3. There were BOTH effects, which cannot be separated or evaluated individually, now.

The two environments did indeed differ, as far as clay deposition was concerned, and the hydrofluoric acid treatment could not have caused this one difference.

The presence or absence of clay provides some other pertinent information: at times when clay accumulation was large, wave energy levels must have been relatively low (perhaps, but not necessarily, on a tidal flat). Therefore the clay data, alone, suggest an oscillation between two sets of conditions. The question that remains is: Do any of the available granulometric parameters also indicate this, and, if they do, can they provide a better description than merely "change of energy level"?

Of 10 different granulometric cross-plots, five show no difference, four make clear distinctions (how much of this, if any, is due to the acid treatment?), and one is indeterminate. Some of the distinctions are due to the clay, which is not present in the quartzites, but not all of them can be explained so readily.

Z-test

The Z-test permits a comparison of two different data sets, in an effort to see whether they are likely to have had either different, or similar, origins (Dixon and Massey, 1957, p. 23-ff). For the present study, the first four moment measures from the suite of washed sandstones (six samples), and the same four parameters from the suite of disaggregated quartzites (six samples), were compared with each other. The results are as follows (P is the probability that the similarities could be due to chance):

Mean	P<0.000 01
StndDev.	P<0.000 01
Skewn.	P<0.000 01
Kurtosis	P<0.000 01

The suite standard deviations for these parameters are very small, so the similarities that are indicated are not a matter of having so much scatter that anything and everything fits. For the first three moment measures, standard deviation values are less than 0.1, and for the kurtosis they are less than 0.6. On the other hand, the number of degrees of freedom is small (12 - 2 = 10), and a larger number of samples would be needed in order to make a better analysis.

For each parameter, the exceedingly low probability (P) indicates that the similarity between the two suites is not due to chance. That is, at the level of 0.00001, the two suites appear to be alike. It should be noted that not a single parameter supports the idea that similarities are due to chance. These numbers are taken as evidence that acid treatment did not cause a significant difference between the two suites, but the number of samples is so small that one cannot yet accept this proposition as proven.

CONCLUSIONS

The general environment of deposition of the Tallahatta Formation, at the places where it was sampled, includes: (a) low-energy beach and shallow near-shore marine water, (b) settling in shallow water, and (c) wind activity.

Two kinds of sandy rocks, quartzites (silica cement in quartzose sandstones) and argillaceous sandstones, are found in the exposures. The primary difference between these two is the presence or absence of silica cement (alternatively, the absence or presence of clay), and this in turn indicates that the initial deposit, in the one case, was a clean sand, whereas in the other case it was a dirty sand. The absence of clay, in the clean sand, permitted accumulation of silica cement at a later time.

The presence of clay in the argillaceous sands may indicate proximity to an important clay source, such as a stream, or perhaps changes in the local wave energy level. Channels in the Tallahatta would support the first of these two suggestions; none was seen. Therefore a change in wave energy level, from time to time, can be inferred.

Does the granulometry of the sand fraction in the quartzites differ significantly from that of the sands in the argillaceous sandstones? If so, this fact might provide additional information about the environment of deposition. The Z-test does not provide any support for this idea, and it appears, at first glance, that the two data sets are essentially identical. Unfortunately, the number of samples is not very large, so it is not now possible to give a clear, simple answer to the question. But it is thought that hydrofluoric acid treatment had no significant effect on the framework grains (Schultz, 1980; Folk, 1989). If there was no important effect from the acid treatment, then the two rock types represent the same depositional conditions.

ACKNOWLEDGMENTS

David T. Dockery III, of the Mississippi Geological Survey, was kind enough to guide the writer to a number of Tallahatta exposures in the general vicinity of Meridian, Mississippi. This necessary assistance is greatly appreciated.

COMPUTER PROGRAMS

The two computer programs, GRAN-7 and SUITES, can be furnished upon request, without cost, as paper print-out, or on a high-quality 3.5" double density disc, formatted and supplied by the person making the request. Each of these two programs operates inside the system GWBASIC, on a DOS platform, but GWBASIC cannot be supplied by the present writer.

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Table 1. Muddy sandstone, Tallahatta Formation, Mississippi

	Mean	S.D.	Skew	Kurt.	Fifth	Sixth	T. of F.
1-M	3.117	1.373	.037	1.776	.02	3.495	.28898
2-M	2.793	1.386	.477	1.924	1.645	4.389	.23502
3-M	2.727	1.372	.475	2.055	1.739	5.138	.21245
4-M	3.034	1.407	.217	1.734	.488	3.459	.28383
5-M	2.767	1.359	.412	2.09	1.478	5.232	.21188
6-M	3.023	1.344	.311	1.809	.896	3.728	.26992

Table 2. Washed sands, Tallahatta Formation, Mississippi

	Mean	S.D.	Skew	Kurt.	Fifth	Sixth	T. of F.
S-1	2.525	1.007	.041	2.139	1.218	7.669	.06542
S-2	2.278	.983	.728	3.249	6	19.058	.05639
S-3	2.287	1.026	.616	3.103	4.876	16.637	.05986
S-4	2.387	.97	.443	2.971	3.984	15.738	.04797
S-5	2.314	1.002	.444	3.042	3.944	15.907	.05172
S-6	2.473	.959	.57	3.129	4.911	16.742	.06697

Table 3. Quartzites, Tallahatta Formation, Mississippi

	Mean	S.D.	Skew	Kurt.	Fifth	Sixth	T. of F.
Q-1	2.409	.727	1.254	6.293	17.613	68.419	.04169
Q-2	2.316	.778	1.16	5.722	15.18	57.939	.04048
Q-3	2.314	.696	1.196	6.786	19.687	85.182	.03065
Q-4	2.323	.759	1.047	5.623	14.616	58.195	.03588
Q-5	2.378	.903	1.184	5.008	11.423	37.176	.07219
Q-6	2.34	.71	1.138	6.333	17.577	74.355	.03279

Table 4. Quartzite, pan fraction removed; Tallahatta Fm., Miss.

	Mean	S.D.	Skew	Kurt.	Fifth	Sixth	T. of F.
R-1	2.323	.564	.05	3.24	.227	15.965	.01011
R-2	2.226	.613	.082	2.954	.007	13.787	.00825
R-3	2.247	.56	-.02	3.414	-.875	19.784	.00661
R-4	2.245	.615	.013	2.916	-.357	13.644	.0078
R-5	2.214	.641	.036	3.163	.226	14.445	.01434
R-6	2.272	.575	.013	3.262	-.688	17.622	.00788

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NEW PUBLICATION BY THE OFFICE OF GEOLOGY

THE STREPTONEURAN GASTROPODS, EXCLUSIVE OF THE STENOGLOSSA, OF THE COFFEE SAND (CAMPANIAN) OF NORTHEASTERN MISSISSIPPI

The Mississippi Office of Geology announces the publication of Bulletin 129, "The Streptoneuran Gastropods, Exclusive of the Stenoglossa, of the Coffee Sand (Campanian) of Northeastern Mississippi," by David T. Dockery III.

Bulletin 129 reports on a hundred species of gastropods from the Upper Cretaceous deposits of Lee County, Mississippi. These fossils are among the best preserved gastropods of their age known anywhere. The text describes the age, depositional environment, and stratigraphy of the Coffee Sand; it then reviews gastropod classification. Next is a systematic description of the Coffee Sand gastropods, illustrated with 42 plates. This publication will be much sought after by professional paleontologists around the world. The excellent figures on the plates will be of immense help to geologists and amateur collectors in identifying the fossil gastropods they find in the Cretaceous deposits of northeastern Mississippi.

Bulletin 129 may be purchased from the Office of Geology at Southport Center, 2380 Highway 80 West, Jackson, for $15.00 per copy. Mail orders will be accepted when accompanied by payment ($15.00, plus $1.50 postage and handling for the first copy and $.50 for each additional copy). Send mail orders (with check or money order) to:

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INSECTS, SPIDERS, AND PLANTS FROM THE TALLAHATTA FORMATION (MIDDLE EOCENE) IN BENTON COUNTY, MISSISSIPPI

John E. Johnston
910 Reed Road
Smyrna, Georgia 30082

ABSTRACT

Fossil insects and spiders are reported for the first time from the middle Eocene Tallahatta Formation in western Benton County, Mississippi. Associated with the fauna is a variety of fossil plants. The fauna and flora occur within a thin siltstone layer separating underlying sands from overlying silty clays. Preservation of the flora varies from impressions to compressions and in some cases includes preservation of the original organic green leaf material. Plant material found includes leaves, flowers, fruits, seeds, and leaf-spot fungi. Preservation of the fauna varies from impressions to molds and casts. Insects recovered include beetles (Coleoptera), ants (Hymenoptera), termites (Isoptera), phantom midges (Diptera), dragonflies (Odonata), damselflies (Odonata), caddisfly larval cases (Trichoptera), and larvae; evidence of insect activity includes insect-damaged leaves. Many of these fossil insects have never been reported from Eocene-aged sediments of the southeastern United States. The spiders are the oldest spiders so far recovered from the Tertiary System in Mississippi.

INTRODUCTION

This paper reports the discovery of the first insects and spiders of Eocene age found in Mississippi. The importance of this discovery is increased by their association with a variety of plant fossils. The fauna and flora were discovered in a clay pit in northwestern Benton County (Text-Figure 1) and occur within a thin siltstone layer separating underlying fine-grained, well-sorted, cross-stratified sands from overlying noncalcareous, thinly bedded to massive, silty to sandy clay. This siltstone layer occurs within the upper portion of the Tallahatta Formation of the middle Eocene Claiborne Group. The fauna collected include beetles, ants, termite wings, damselfly naiads (nymphs), dragonfly wings, caddisfly larval cases, phantom midge pupae, insect larvae, various insect body parts, and spiders. The evidence of insect activity is present in the form of insect-cut or damaged leaves. The flora collected include a variety leaves, flowers, seeds, and fruits.

Fossil leaves from Eocene sediments of the southeastern United States have been extensively described by Berry (1916, 1924, 1930, 1941), Knowlton (1927), Dilcher and Dolph (1970), and Dilcher and Daghlian (1977). Although these Eocene-aged deposits have yielded some of the best preserved and greatest variety of early Tertiary floras of North America, the occurrence of fossil insects is unusually sparse. Insects described from the southeastern United States have been from Eocene sediments of Texas, Arkansas, and western Tennessee. Saunders et al. (1974) reported insect inclusions in middle Eocene amber from central Arkansas. The orders Hemiptera (Homoptera), Diptera, and Hymenoptera comprise the majority of all insect inclusions. Sparsely represented are the orders Collembola (springtails), Orthoptera (cockroaches), Trichoptera (caddisflies), and Coleoptera (beetles). Spiders have also been found as inclusions in the amber but are scarce. The insects previously described from western Tennessee include an ant wing (Carpenter, 1929), a termite wing (Collins, 1925), beetle elytra, or wing covers (Wickham, 1929), and caddisfly larval cases (Berry, 1927, 1930). Evidence of insect activity has also been described and includes insect-cut leaves (Berry, 1931; Brooks, 1955) and insect galls on leaves (Brooks, 1955). Cockerell (1923) described an ant wing and a damselfly wing (incorrectly identified as a dragonfly wing) from the upper Eocene Jackson Group in Texas. Based on the work of Berry (1916, 1931), all of the Eocene-aged insects described from western Tennessee were noted as being from sediments within the Holly Springs Formation of the lower Eocene Wilcox Group. However, Dilcher and Dolph (1970) stated that recent mapping indicates at least some of these deposits in western Tennessee are within the middle Eocene Claiborne Group.

The purpose of this paper is to announce the discovery of the first known fossil insect locality in Mississippi and to describe some of the fauna and flora discovered. Fossil insects are uncommon, but their occurrence with leaves, flowers, and fruits makes this find even more unusual. Subsequent field investigations will provide a more detailed study of the fossil fauna and flora.

GEOLOGY

All fauna and flora were collected from the Holly Springs Brick and Tile Company clay pit located six miles northeast of Holly Springs in Benton County, Mississippi (Holly Springs

SE 7.5' Quadrangle, NE ¼, NE ¼, Sec. 6, T.3S., R.1W.). This pit, known as the Bolden Pit, covers approximately 25 acres and has been mined for brick clay since 1965. The fossils occur in a thin siltstone layer exposed in a drainage ditch in the south-central portion of the pit.

Lowe (1913) referred to the entire exposed section in Marshall County, which borders Benton County on the west, as belonging to the Wilcox Group, except for the Citronelle Formation, the loess, and recent deposits. Within the Wilcox Group, Lowe (1913) recognized two formations: the Ackerman and the Holly Springs. Lowe (1913) applied the name Holly Springs Formation to include all sand overlying the Ackerman Formation. Vestal (1954) noted that subsequent studies showed the Holly Springs Formation did not comprise a single lithostratigraphic unit but consisted of portions of the Meridian, the Tallahatta, and the Kosciusko formations. These three formations comprise the middle Eocene Claiborne Group in Benton and Marshall counties.

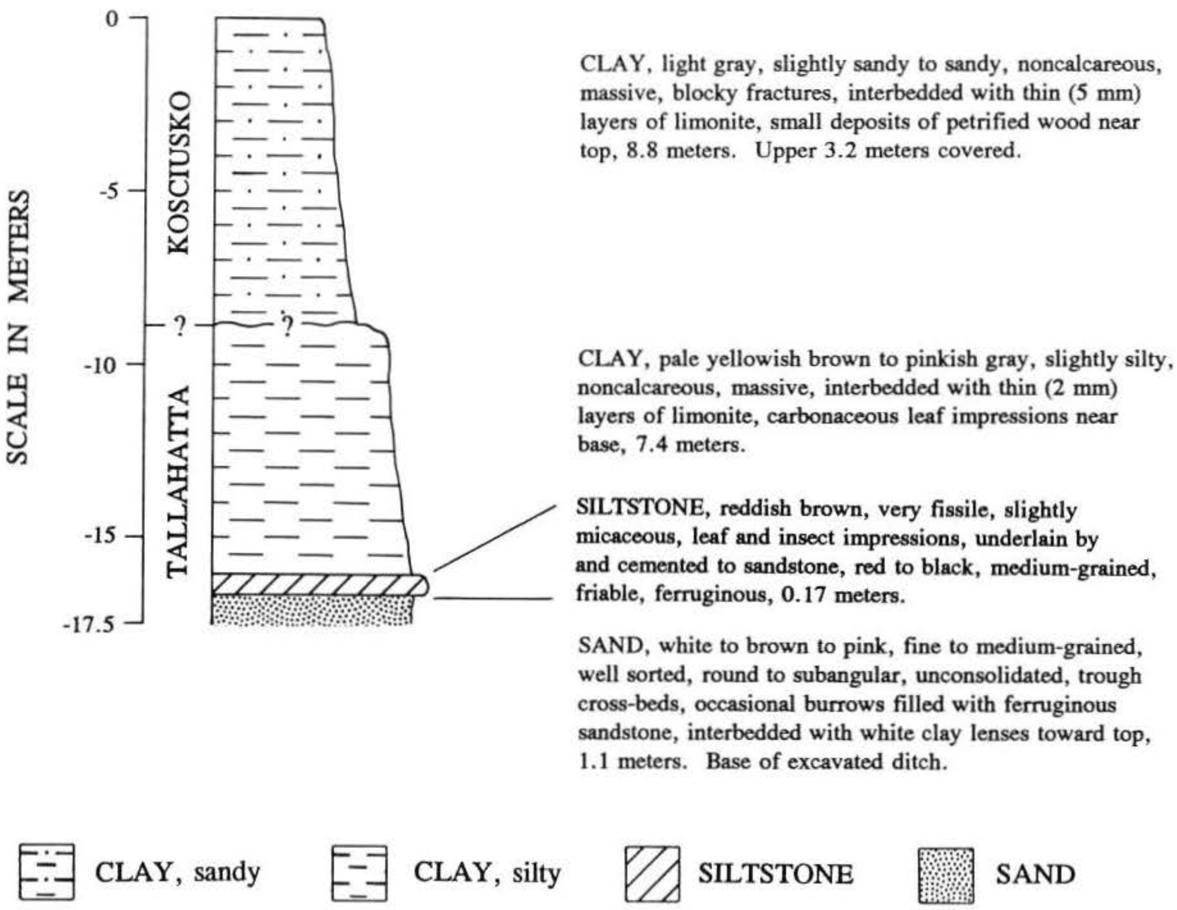
Text-Figure 1. Location of the Bolden Pit in Benton County, Mississippi.

Lusk (1956) stated that the Tallahatta Formation in Benton County is composed primarily of a fine to very coarse, pebble-bearing, micaceous quartz sand containing white clay balls. In some areas, the white clay occurs in large pockets or lenses exceeding 30 feet in thickness. In adjacent Marshall County, Vestal (1954) described the Tallahatta Formation as 200 feet or more thick and of gray to brown to black to white, well-bedded clay shale; fine, micaceous, white to yellow to red to brown sand; fine-grained ferruginous sandstone; and crusts and thin layers of varicolored silty limonite or limonitic siltstone. Approximately 3 miles west of Holly Springs, Vestal (1954) described a fifty-foot (15.2 meter) interval of Tallahatta as being composed of layers of silty sand, clay, and silty limonite. The sand and white clay are separated by partings of brightly colored red, yellow, pink, white, and brown silty limonite or limonitic siltstone. Near this exposure, a six-foot (1.8 meter) cliff is capped with two- to three-inch-thick slabs of silty limonite. Vestal (1954) described a clay pit just east of Holly Springs that exposed eight feet of white or cream-colored, laminated, leaf-bearing Tallahatta clay overlain at an elevation of 580 feet by red-brown Kosciusko sand.

The Kosciusko Formation unconformably overlies the Tallahatta Formation. Lusk (1956) described the Kosciusko Formation in Benton County as a reddish-brown, coarse sand containing some ferruginous sandstone. In some places, the lower portion of the Kosciusko contains reworked white clay from the underlying Tallahatta. Vestal (1954) described the Kosciusko in Marshall County as coarse to fine, white to brown, massive to cross-bedded, micaceous sand and sandstone. He also noted that the unit contains reworked clay and shale toward the base.

According to the geologic map of Benton County (Lusk, 1956), the fossil-bearing siltstone layer in the Bolden Pit is located just below the exposed Tallahatta-Kosciusko contact. The topographic map shows the elevation in the Bolden Pit area, prior to mining, to have been 580 to 600 feet above sea level. Since the siltstone layer occurs 53.25 feet (16.2 meters) below the top of the exposure, the elevation of the layer is approximately 530 to 550 feet above sea level. Lusk (1956) described an exposed Tallahatta-Kosciusko contact approximately 4 miles due north of the Bolden Pit, and at an elevation of 580 to 600 feet, as white, argillaceous, sandy silt of the Tallahatta overlain by weathered red-brown Kosciusko sand. Ten feet below the contact, at the base of a white silt layer, is a very thin ferruginous siltstone overlying a very fine, varicolored micaceous sand.

The measured section in the south-central portion of the Bolden Pit measures 17.5 meters (57.5 feet) from the base of the drainage ditch to the top of the exposure (Text-Figure 2). This section consists of a fine-grained, well-sorted, white to pink, cross-bedded, silty sand overlain by a thinly bedded to massive, pale yellow to light gray, slightly silty to sandy clay with carbonaceous leaf impressions. Toward the top of the exposure, the clay becomes progressively more sandy. Numerous localized deposits of petrified wood occur within the sandy clay approximately 6.4 m (21 ft) below the top of the exposure. The sand is separated from the overlying clay by a 5-cm-thick layer of sandstone and siltstone cemented as one rock. The lower half of this layer is a ferruginous sandstone and the upper half a brown to red, very fissile siltstone. All flora and fauna collected at the Bolden Pit occur in the siltstone portion of this layer. Lusk (1956) described a similar siltstone/sandstone layer separating the Tallahatta Formation from the overlying Kosciusko Formation at an exposure approximately 4 miles due north of the Bolden Pit. However, the layer that Lusk described consisted of siltstone overlain by a ferruginous sandstone. The top of the siltstone exhibits tan to yellow, sinuous or roughly circular patterns. Vestal (1954) described a limonitic siltstone layer with similar features at an exposed Tallahatta-Kosciusko contact in the western portion of Marshall County and stated that such patterns may have been produced by the drying and shrinking of iron oxide-saturated silt.



Text-Figure 2. Measured section in the south-central portion of the Bolden Pit.

At the southern edge of the pit, the horizontal siltstone layer tilts sharply upward and then tilts sharply back to horizontal. The vertical distance between the two offset horizontal layers is 2.8 meters (9.2 feet). The exposure shows the cross-bedded sand adjacent to the horizontally bedded clay on the same level with the two lithologies separated by the sharp diagonal contact of the siltstone layer. This exposure compares well with one described by Vestal (1954) 7 miles northwest of Holly Springs, in which a red-brown, cross-bedded sand was separated from a horizontally-bedded, white silty shale by a sharp diagonal contact, possibly marking the Tallahatta-Kosciusko contact. All of the fauna and flora occur in the lower horizontal portion of the siltstone layer. No fossils have been found in either the diagonal or the upper horizontal portion of the siltstone. Additionally, this nonfossiliferous portion of the layer exhibits a polished and striated surface very similar to that which results from friction due to movement along a plane.

South of the pit the statigraphy becomes more uniform. Approximately 25 meters (82 feet) south of the first measured section, the entire exposed 7.1-meter (23.3 feet) section consists of red to white to brown, fine- to coarse-grained, subrounded to rounded, well-sorted, strongly cross-bedded sand. Numerous vertical burrows filled with ferruginous sandstone occur throughout the sand.

The Bolden Pit exposes the top of the Tallahatta Formation. The sand and sandstone typical of the Kosciusko Formation are not present above the clay. However, the sandy clay near the top of the exposure may be reworked Tallahatta clay and would therefore be the base of the Kosciusko Formation. If so, the contact between the Tallahatta Formation and the Kosciusko Formation may be a bench-forming layer 7.4 meters (24.3 feet) above the siltstone layer.

FLORA

Preservation of flora from the Bolden Pit varies from impressions, in which no organic matter is preserved and only the outline of the veins and margin remain, to compressions with preservation, in some cases, of the original organic green leaf material. Some of the leaves and most of the seeds and fruits exhibit a bright yellow color or stain, which appears to have replaced the original material. Many of the leaves are not merely two-dimensional impressions but are three-dimensional and exhibit folds and convolutions. Multiple leaves attached to a single stem and small delicate flowers have also been found.

Spots of various shapes and sizes occur on many of the leaves and may represent fossil leaf-spot fungi (Plate 1, Figure 1). Berry (1916) described and illustrated several new species of fossil fungi but noted that the identification of some of these fossils was tentative because scale insects and insect galls may resemble epiphyllous fungi when preserved on fossil leaves. However, he stated that undoubted fungi are preserved and he assigned the genus name *Caenomyces* for Cenozoic-aged leaf-spot fungi of uncertain botanic affinities. Based on the descriptions and illustrations that Berry (1916) provided, the leaf-spot fungi *Caenomyces pestalozzites* Berry, *Caenomyces annulata* Berry, and *Caenomyces laurinea* Berry commonly occur on fossil leaves from the Bolden Pit.

FAUNA

Phylum ARTHROPODA

Class INSECTA

Order COLEOPTERA (Beetles)

Whereas most insects possess two pairs of wings, the fore wings and the hind wings, the fore wings in the beetles have been modified to form wing-covers, called elytra. Elytra are hard, horny or leathery wing-covers which meet in a straight line down the back to form covers for the hind wings. The majority of fossil Coleoptera consists of these individual elytra or parts of elytra combined with crushed and distorted portions of the head and thorax. Carpenter (1992) stated that classification of Coleoptera into suborders and families is based mainly on details of structures such as antennae, coxae, mouth parts, and tarsi, which are rarely preserved in fossil insects. However, traditional classification of fossil Coleoptera has been based on comparison of body form with that of extant Coleoptera. Carpenter (1992) stated that this comparison of similar body form has resulted in erroneously assigning most of the fossil Coleoptera to extant genera.

Wickham (1929) described three new species of beetles based on four individual elytra collected from lower Eocene Wilcox clays in western Tennessee. (Dilcher and Dolph (1970) stated that these clays may be within the middle Eocene Claiborne Group.) The classification of these new species was based on size, shape, and ornamentation, such as costal arrangement, of the elytra. Saunders et al. (1974) reported beetles as inclusions in amber from the middle Eocene of Arkansas.

Coleopteran material from the Bolden Pit consists of 14 complete, or nearly complete, beetles (Plate 1, Figure 2) and 12 individual elytra (Plate 1, Figure 3). Preservation of both the complete beetles and individual elytra varies from lignitized impressions to yellow-stained, three-dimensional molds and casts. The best preserved complete specimen (Plate 1, Figure 2) clearly exhibits the antennae, head, pronotum, and elytra. Elytral shape on this complete specimen, based on beetle-shape nomenclature of Dillon and Dillon (1961), is elongate-oblong, moderately robust. Elytral ornamentation consists of carina with very fine granules and intervals with coarse, square punctures. The shape of individual elytra ranges from elongate-ovate slender to elongate-oblong slender to elongate-oblong, moderately robust. Ornamentation on these individual elytra ranges from striae with coarse punctures to striae with no punctures.

A portion of one leaf exhibits two arched rows of small, elliptically-shaped nodes (Plate 1, Figure 4). These nodes are identified tentatively as beetle eggs, based on the work of Lewis and Carroll (1991), in which they identified flea beetle (Chrysomelidae) eggs on alder leaves from middle Eocene-aged lacustrine rocks in northeastern Washington state. The eggs from the Bolden Pit average 1 mm in length and 0.5 mm in width. The outer arch is composed of 11 eggs while the inner arch is composed of five eggs. The preserved leaf portion onto which these eggs were laid may be too small for accurate identification.

Order HYMENOPTERA, Family FORMICIDAE (Ants)

Cockerell (1923) described a new species of ant, *Formica eoptera* Cockerell, based on a solitary wing from the upper Eocene Fayette Sandstone (Jackson Group) in Texas. Carpenter (1929) described a new genus and species of ant, *Eoponera berryi* Carpenter, based on a fore wing discovered in supposedly lower Eocene (Wilcox Group) clays of Tennessee. Carpenter stated that the size of the *E. berryi* wing, 26 millimeters long and 7 millimeters wide, indicates that the wing-span must have been at least 57 millimeters. Wilson (1985) described three new species of fossil ants from a middle Eocene amber deposit in central Arkansas.

Ants from the Bolden Pit range from complete insects with and without wings (Plate 1, Figures 5, 6, and 7) to solitary wings (Plate 2, Figure 8), the latter being more common. Preservation ranges from faint imprints to carbonized impressions. The largest complete specimen with attached wings (Plate 1, Figure 5) measures 16 mm from the anterior end of the head to the posterior end of the gaster (the gaster is equivalent to the anterior half of the abdomen). The gaster measures 8 mm long and is composed of five tergites, or segments. The petiole, which is the constricted first gastral segment connecting the gaster to the metathorax, is easily visible. Both the hind pair and fore pair of wings are spread away from the body so that the venation of all four wings is visible. The individual fore wings and hind wings measure 10 mm and 6.5 mm in length, respectively. The wings on this specimen, like the majority of the ant wings from the Bolden Pit, are so well preserved as to allow identification of the veins and cells. Wheeler (1913) stated that although wings have not been used to a great extent in descriptive work on ants, the venation on the fore wings exhibits important generic or specific characters and is indispensible in the study of fossil ants.

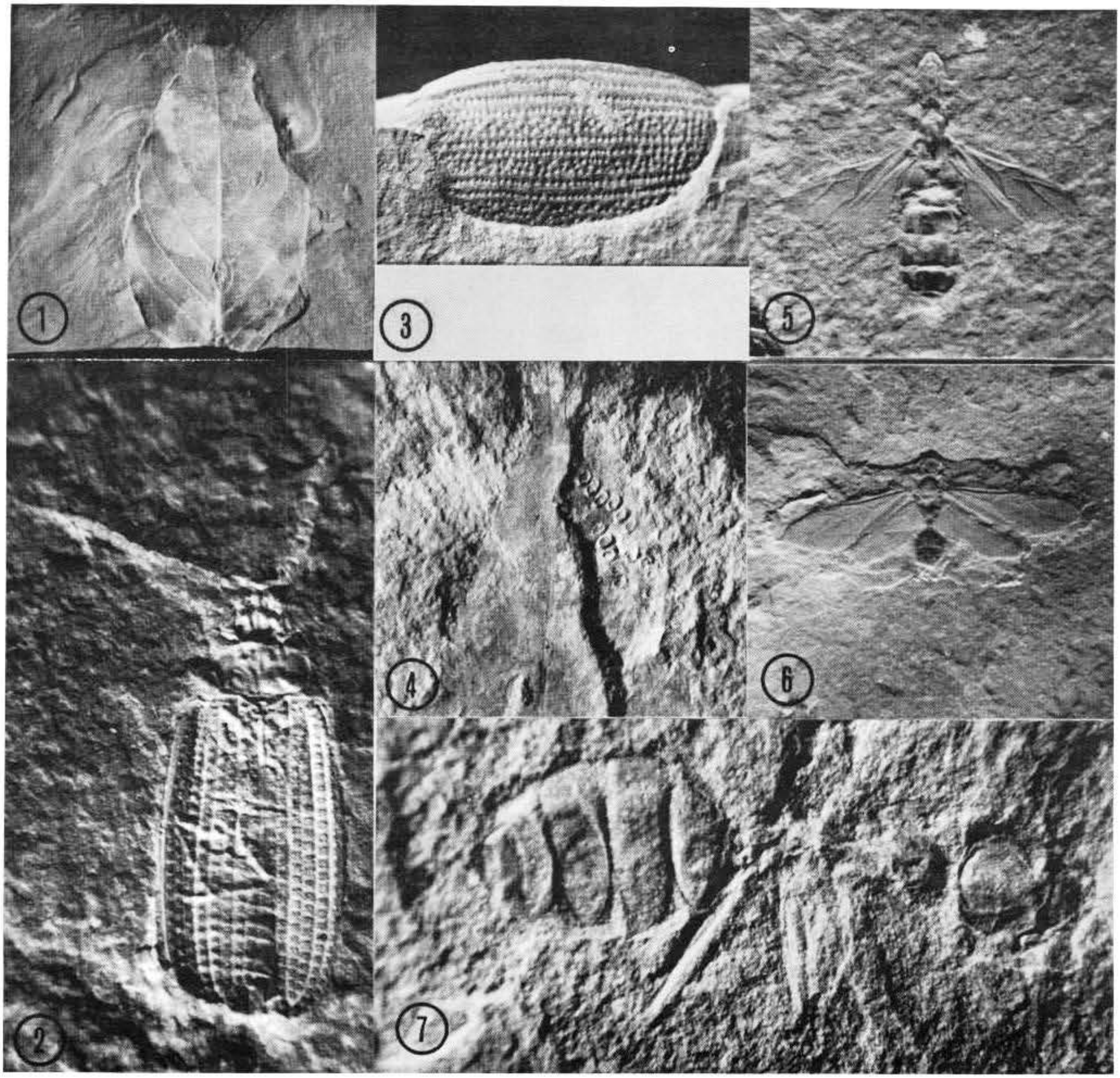


Plate 1

Figure 1. Leaf infested with the leaf-spot fungus *Caenomyces annulata* Berry along the midrib and veins. 0.8X. BC1-181. Figure 2. Complete beetle with dorsal side exposed. 8.3X. BC1-240. Figure 3. Beetle elytron with coarse punctures. 6.5X. BC1-318. Figure 4. Beetle eggs on leaf fragment. 2.7X. BC1-334. Figure 5. Ant with the hind pair and fore pair of wings attached. 2X. BC1-303B. Figure 6. Ant with the hind pair and fore pair of wings attached. 2.4X. BC1-361. Figure 7. Side view of an ant without attached wings. 14.5X. BC1-247.

Order ISOPTERA (Termites)

Collins (1925) named and described a new species of primitive termite, *Mastotermes wheeleri* Collins, based on a solitary left fore wing from the lower Eocene clays of western Tennessee. The *M. wheeleri* Collins specimen from western Tennessee has subsequently been renamed *Blattotermes wheeleri* Collins (Carpenter, 1992). The *B. wheeleri* wing measures 26 mm long and 7.9 mm at maximum width. The anterior and posterior margins are nearly equally curved with a broadly rounded tip.

Two solitary termite wings have been recovered from the Bolden Pit. The best preserved wing is a right fore wing, which measures 17 mm in length, 7 mm in maximum width, and has a broadly rounded tip (Plate 2, Figure 9). Although approximately 2 mm of the basal end is missing, overall preservation is excellent and, according to Krishna and Wessner (1969), should allow identification to the genus level. However, identification of the species may be more difficult, as Krishna and Wessner (1969) noted that venation of termite wings may vary from one individual to another within a species.

Order ODONATA, Suborder ZYGOPTERA (Damselflies)

Cockerell (1923) described a new genus and species of damselfly, *Eodichroma mirifica* Cockerell, based on a solitary wing from the upper Eocene Fayette Sandstone (Jackson Group) of Texas. Although Cockerell (1923), and subsequently Berry (1924), referred to this wing as a dragonfly (Order Anisoptera), he stated that it belongs to the Order Zygoptera, which are damselflies. In dragonflies (Order Anisoptera), the hind wings are larger than the fore wings, are somewhat different in shape, and extend horizontally at right angles to the body when at rest. The damselflies (Order Zygoptera) have two pairs of wings similar in form and are either folded parallel with the body when at rest or tilted slightly upward.

Damselfly remains from the Bolden Pit consist of carbonized impressions of complete naiads (nymph-like stage of metamorphosis) and portions of naiads (Plate 2, Figure 10). These damselfly naiads were identified based on the three plate-like tracheal gills at the caudal (posterior) end of the body. Damselfly naiads were distinguished from mayfly naiads (Order Ephemeroptera), which they closely resemble, by the absence of tracheal gills on the abdominal segments. The length of complete naiads ranges from 5 mm to 9.5 mm. Also discernible on the complete naiads are the heads, legs, and segmented abdomen.

Order ODONATA, Suborder ANISOPTERA (Dragonflies)

Dragonfly remains from the Bolden Pit consist of molds and casts of two solitary wings. One wing is complete, whereas the apex, or end margin, on the other wing is missing. The complete wing is broadly rounded, only slightly convex, and measures 29 mm in length and 7 mm at the maximum width (Plate 2, Figure 11). The presence of a triangle and supratriangle toward the basal, or attached, end identifies this specimen as an anisopteran, or true dragonfly (Jarzembowski, 1988). Both the triangle and the supratriangle lack crossveins. The anal vein terminates at the hind angle of the triangle, which indicates that this is a fore wing (Needham and Westfall, 1955). The convexities and concavities of the veins, which give the wing a corrugated effect in order to strengthen it, are preserved in relief. According to Comstock (1949), Needham and Westfall (1955), and Carpenter (1992), the position, shapes, and sizes of the various structures within the wing provide the basis for the classification of fossil Odonata. Since all of the veins, crossveins, and cells are preserved and identifiable, identification to the genus and species level may be possible.

Order TRICHOPTERA (Caddisfly Larval Cases)

Caddisfly larvae construct open-ended tubular cases that cover their bodies, except the head and legs. The materials used to construct the cases vary from sand grains to ostracod valves to leaves, and the materials are fastened together with silk. To construct cases made of leaves, square-shaped leaf segments are fastened together to form a flat case or are arranged in three planes forming a tube that has a triangular cross section. The caddisfly worm occupies the case throughout the larval and pupal stages. Once it completes the pupal stage and becomes an adult, it abandons the case, immediately swims to the surface, and takes flight.

In a monograph on the lower Eocene flora of southeastern North America, Berry (1916) described some fossils from the Holly Springs Formation in western Tennessee which he identified as isopods (aquatic crustaceans with a flat, oval body). Berry (1927) later recognized leaf-like venation on the segments of these fossils and concluded that they were not isopods but a previously undescribed type of caddisfly larval case. He assigned these cases to the family Limnophilidae (actually the Limnephilidae) and recognized them as a new genus and species, which he called *Folindusia wilcoxiana* Berry. These cases were described as large, flat, two-faced, and constructed entirely of cut leaf fragments. Berry (1941) figured, but did not describe, another caddisfly larval case that was also constructed of leaf fragments (possibly *Folindusia* sp.) from lower Eocene Wilcox sediments in Kentucky.

Berry (1930) described, but did not figure, two additional caddisfly larval cases from the Eocene of Tennessee. Both cases are straight, tubular, and constructed of quartz sand grains and small plates of mica. Berry stated that the remains are too incomplete for naming.

Sixty-five complete and nearly complete caddisfly larval cases have been collected from the Bolden Pit (Plate 2, Figures 12 and 13). The degree of preservation varies greatly and ranges from red-brown and yellow-stained impressions to

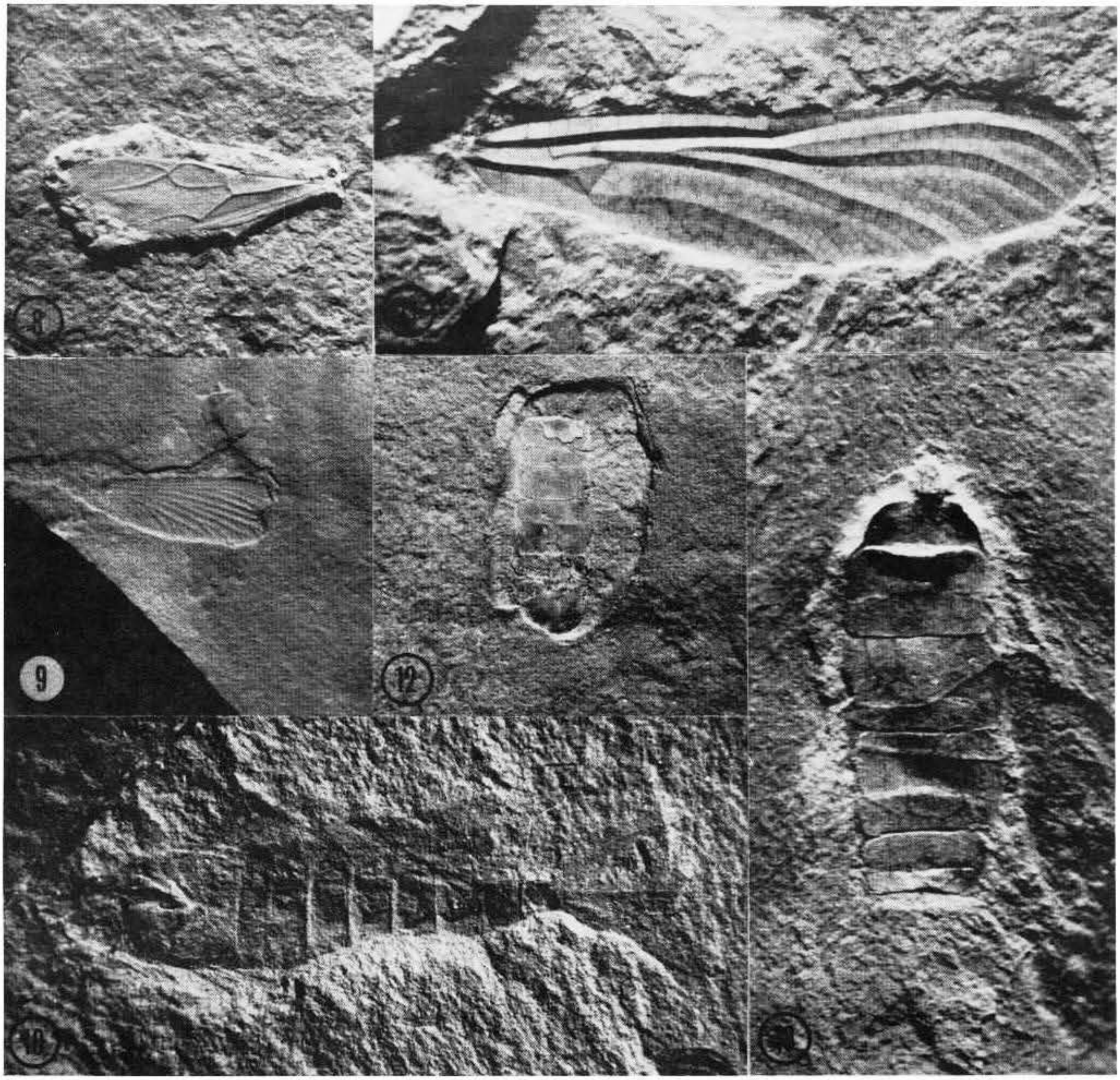


Plate 2

Figure 8. Ant fore wing. 2.8X. BC1-025B. Figure 9. Termite fore wing. 1.5X. BC1-026. Figure 10. Damselfly naiad showing three plate-like tracheal gills at the caudal (posterior) end of the body. 9.6X. BC1-162. Figure 11. Dragonfly fore wing. 3.4X. BC1-010B. Figure 12. Caddisfly larval case with small fragment of original leaf material on top segment. 1.5X. BC1-062. Figure 13. Caddisfly larval case with head of larva protruding from anterior, or top, segment. 3X. BC1-306.

cases with original green organic leaf material. On complete cases, the length ranges from 12 to 31 mm, width at the middle ranges from 5.5 to 18 mm, and width at the cephalic (anterior) end ranges from 3 to 17 mm. The cases are constructed of three to eight leaf segments (with the majority consisting of four segments) attached end to end, with the ends slightly overlapping each other. Two layers, one on top of the other with the edges attached, form a complete case. The wide range of case sizes may be a result of larval growth. As the larva grows, either the case is enlarged or the larva abandons it and constructs a new and larger case (Borror and White, 1970). Many cases had one or both ends missing or covered, which made precise overall measurements impossible. However, measurements available on these incomplete specimens were comparable to those made on complete cases. Although most of the cases preserved had presumably been abandoned, two cases still retained the larvae as evidenced by the larva heads protruding from the case. Based on the work of Wiggins (1977), these fossil cases closely resemble the cases made by recent caddisflies of the genera *Phyllocius* (Family Calamoceratidae) and *Clostoeca* (Family Limnephilidae). Although the cases are found throughout the siltstone layer, they are more abundant in a lower, coarser-grained portion of the layer just above the cemented ferruginous sandstone. In several instances, especially in this lower, coarser-grained portion, two or more cases were found within a few centimeters of each other.

Order DIPTERA, Family CHAOBORIDAE (Phantom Midge Pupae)

Crosskey (1980) stated that the Family Chaoboridae was formerly considered a subfamily of the Family Culicidae (mosquitoes) but is now treated as a separate family. A fossil Chaoboridae, *Corethra exita* Scudder, was described from the Eocene of Colorado, but Edwards (1923) stated that so little of the specimen was preserved that it may belong to the Culicidae or the Tipulidae (crane fly). Carpenter (1992) also grouped the Chaoboridae with the Culicidae and stated that the oldest recorded fossil Chaoboridae are from the Oligocene of Europe.

Phantom midge pupae and pupal shells occur throughout the siltstone layer and are not concentrated within any particular portion of the layer. The pupae are identified by the respiratory trumpets on the cephalothorax, the segmented abdomen, and the wide fan-shaped anal paddles (Plate 3, Figure 14; Essig, 1942, Figure 271 C.). More common are the pupal shells, which remain after the adult has emerged. These shells retain the abdomen and anal paddles but the cephalothorax is absent because it is destroyed when the adult emerges. The degree of preservation ranges from faint imprints to casts and molds. Based on nearly two hundred specimens collected from the Bolden Pit, the length of pupae (with cephalothorax attached) ranges from 6 to 7 mm while the length of the pupal shell (lacking the cephalothorax) ranges from 4 to 6 mm.

INSECT LARVAE

Insect larvae, common throughout the siltstone, are represented by two primary larval forms: scarabaeiform and vermiform. Scarabaeiform larvae are grub-like with a distinguishable head and thoracic legs, and occur in the metamorphosis of certain Coleoptera (beetles). Vermiform larvae are worm-like and exhibit a well-developed head but no legs, and are common in Diptera (flies and mosquitoes) and Hymenoptera (ants and bees). The larvae collected from the Bolden Pit occur primarily as faint impressions and include both scarabaeiform and vermiform. On many specimens, the head, thoracic legs (when present), and ventral nerve cord have been carbonized and are easily discernible. Several specimens appear to be mosquito larvae, as evidenced by a bifurcating terminal abdominal segment that may represent a respiratory siphon.

MISCELLANEOUS

Two individual insect legs have been found that appear to belong to the Order Orthoptera (cockroaches, grasshoppers, and crickets), based on similarities with living orthoptera, which have legs possessing strongly developed femurs that aid in jumping. One of these orthopteran legs consists of the femur, tibia, and tarsus, whereas the other orthopteran leg consists of the trochanter, femur, and tibia. The strongly developed femur on both legs indicates that the legs, and not wings, may have been the insect's major means of locomotion, because insects which are strong fliers generally have weak legs.

Four solitary insect wings have been recovered, which have not yet been assigned to any particular order. The preservation of the veins and crossveins is excellent and should allow subsequent investigators to identify these wings and assign them to the proper taxa.

Class ARACHNIDA

Order ARANEIDA (Spiders)

Petrunkevitch (1955) stated that fossil spiders have been preserved from the Upper Carboniferous (Pennsylvanian) System but their fossil record is very incomplete. Middle Eocene-aged spiders have been recovered preserved in amber from central Arkansas (Saunders et al., 1974) and as impressions from the Green River Formation in Colorado (Grande, 1984).

Seven fossil spiders have been found in the Eocene-aged sediments of the Bolden Pit, which makes them the oldest spiders recovered from the Tertiary Period in Mississippi. These spiders occur as impressions, casts, and molds. Al-

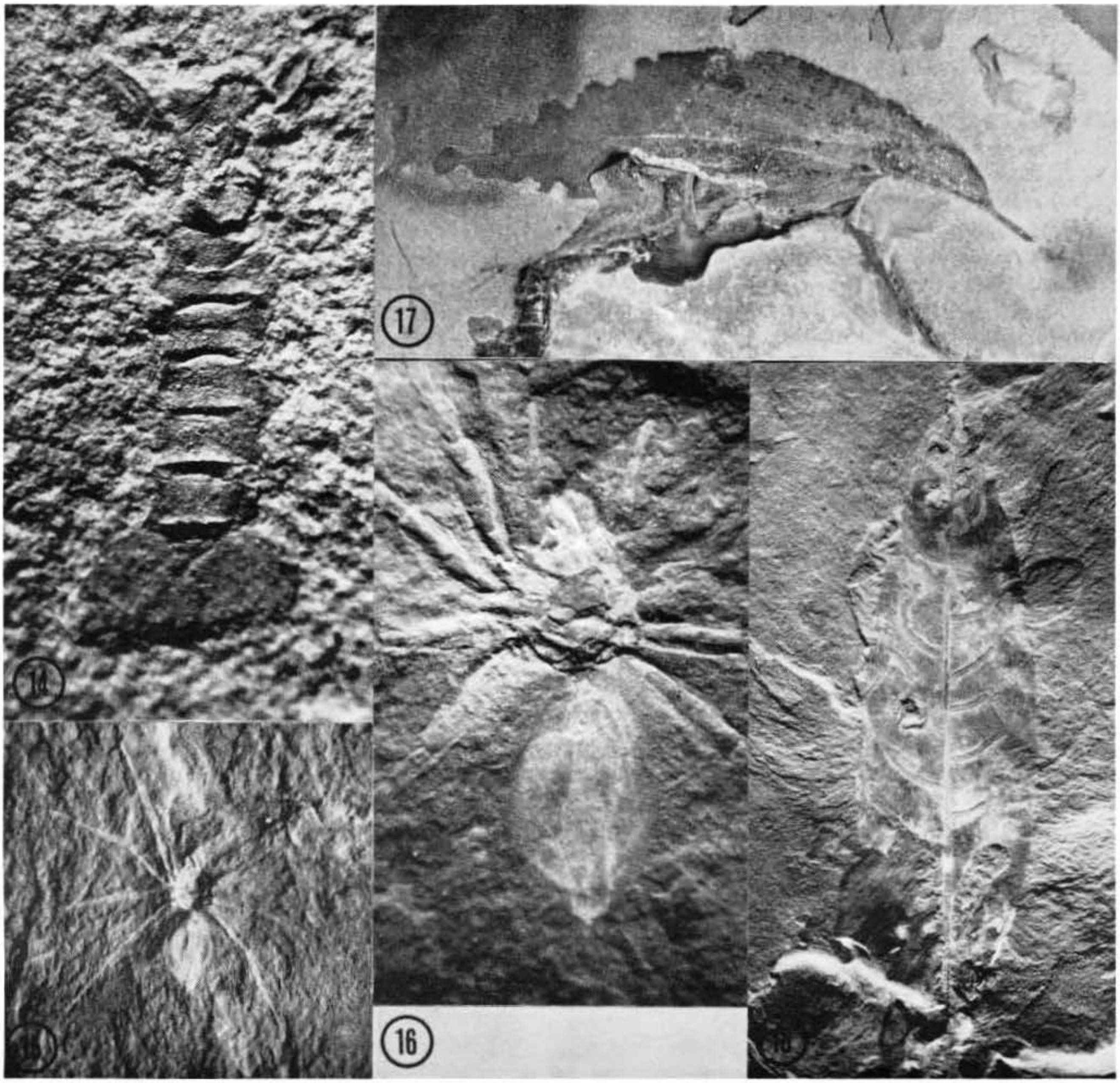


Plate 3

Figure 14. Phantom midge pupa showing anal paddles, segmented abdomen, and respiratory trumpets on cephalothorax. 16X. BC1-112. Figure 15. Spider with dorsal side exposed. 2.3X. BC1-187T. Figure 16. Closeup of specimen in previous figure. 7.4X. BC1-187T. Figure 17. Leaf showing semi-circular cut-outs made by insects. 0.9X. BC1-362. Figure 18. Leaf showing linear-shaped feeding trails made by phytophagous insects crawling on the surface of the leaf. 1.1X. BC1-363.

though preservation is excellent, characters such as internal organs, which are required for correct classification, are missing and placement into suborders may be uncertain (Petrunkevitch, 1955). The largest and best preserved specimen (Plate 3, Figures 15 and 16) measures 9 mm from the anterior end of the cephalothorax, or prosoma, to the posterior end of the abdomen, or opisthosoma, and 22 mm from the end of the first walking leg on the left side to the end of the fourth walking leg on the right side (diagonally across the extended legs). The specimen was buried with the ventral side up but it is the dorsal side that is exposed, as identified by the thoracic groove which is located on the dorsal side of the cephalothorax. Other external characters readily identified are the chelicerae (onto which the fangs are attached) and the pedipalpi (front leg-like appendages located on both sides of the chelicerae). The abdomen lacks any apparent segmentation but exhibits impressions of hair. On several legs, all seven segments can be identified. The legs also appear to have been covered by hair, at least toward the distal end.

INSECT ACTIVITY

INSECT-CUT LEAVES

Berry (1930, 1931, 1941) figured and described insect-cut leaves from the Eocene of Kentucky and Tennessee. The leaf from Tennessee, *Cassia fayettensis* Berry, exhibits one semicircular cut-out along one margin, and the leaf from Kentucky, *Icacorea perpaniculata* Berry, exhibits numerous semicircular cut-outs, 6 to 9 mm in diameter, along both margins. Berry (1931) stated that the cuts may have been made by caddisfly larvae or leaf-cutting bees. Caddis worms would have cut the leaf after it had fallen in the water and used the cut segments to construct larval cases (see discussion under Caddisfly Larval Cases in this paper) whereas leaf-cutting bees, or Megachilidae, would have cut the leaf before it fell and used the segments to line the cells of the nest before depositing eggs.

Brooks (1955) described some insect-cut leaves from a clay lens in the middle Eocene Holly Springs Formation in Tennessee that had been damaged by leaf-cutting bees and phytophagous (plant eating) insects. Brooks (1955) stated that damage caused by leaf-cutting bees is uniform in shape (circular to semicircular) and size and some leaves show scar tissue around the cut, proving that the leaf remained on the tree for some time after it was injured. Leaves with healed wounds could not have been cut by caddisfly larvae, which only cut leaves that have fallen. Brooks (1955) also stated that damage to leaves by phytophagous insects exhibits irregularly shaped cuts.

Several insect-cut leaves have been found within the siltstone layer from the Bolden Pit. Other leaves exhibiting cuts similar to cuts made by insects have been found but it is uncertain whether these cuts were made by insects or if they were damaged by other means prior to or during deposition. Two leaves contain semicircular cut-outs along the leaf margins similar to the cut-outs described by Berry (1930, 1931). One leaf exhibits semicircular cut-outs along the apical (top) half of both margins (Plate 3, Figure 17). The basal exmedial (lower left) portion is partially covered by overlying siltstone obscuring any cut-outs that may be present. The apical admedial (upper right) portion exhibits eight semicircular cut-outs that range from 2 to 4 mm in diameter. The apical exmedial (upper left) portion contains three semicircular cut-outs that are 3 to 4 mm in diameter.

Another insect-cut leaf exhibits narrow, linear cuts within the leaf that extend outward from the main vein, run parallel to second-order veins, and cross higher-order veins (Plate 3, Figure 18). Eight linear cuts occur in the admedial half and ten linear cuts occur in the exmedial half. The lengths of the cuts range from 6 to 13 mm and the width of all cuts is 1 mm. These wounds appear to have been caused by some phytophagous insect crawling on the surface of the leaf and not by a leaf-mining insect (Brooks, 1955).

DISCUSSION

Wolfe (1978) used broad-leafed foliage characters, such as type of margin, size, texture, type of apex, and type of base and petiole, to interpret the Eocene paleoclimate in the southeastern United States. Wolfe (1978) stated that these Eocene plant assemblages from Tennessee and central Mississippi are characteristic of dry tropical vegetation and indicate a drying trend from the Paleocene into at least the middle Eocene. Interpretation of the paleoclimate may be refined based on leaf characteristics of the floral assemblage recovered from the Bolden Pit.

Climatic conditions at the time of deposition can also be inferred from the flora and the seasonal cycles, or stages of development, in the insects. The presence of flowers, seed pods, winged ants, and phantom midge pupae indicates warm temperatures at the time of deposition.

Depositional environments can also be inferred based on the types of preservation. Insects with appendages attached and leaves with organic material preserved indicate that burial occurred rapidly before decomposition could take place. The presence of spiders and terrestrial plants indicates a nearshore depositional environment. The fauna and flora underwent minimum transport since many of the delicate insects and flowers remained intact prior to burial.

Licht (1986) studied fossil spiders from the Florissant Shales, which were deposited very rapidly as volcanic ash, and noted that the legs of most of the specimens are extended. Licht stated that spiders that died prior to deposition have their legs curled inward, and spiders that died suddenly expired with their legs extended in a relaxed position. He concluded that the Florissant spiders were not dead prior to burial but died suddenly as a result of the hot volcanic ash raising the water temperature to a high enough level to kill the spiders. All of the fossil spiders from the Bolden Pit exhibit extended legs, which indicates that they, like those from the Florissant Shales, may have died suddenly. However, the cause of death of the Bolden Pit spiders, unlike those from the Florissant Shales, is uncertain.

Berry (1927) stated that the large, flat, two-face construction of caddisfly larval cases from Eocene sediments of Tennessee prevented capsizing, and he interpreted this to mean that they lived in an area with some current action. Berry (1927) interpreted the general environmental setting of the Eocene in the Kentucky area, based on the flora and caddisfly larval cases, as "a low, abundantly forested, warm temperate coast, with bayou-like stream distributaries emptying into lagoons ponded behind extensive barrier beaches, beyond which the gulf waters were extremely shallow, and not typically marine for a considerable distance." Based on the work of Dodds and Hisaw (1925) and Chamberlain (1975), the cases from the Bolden Pit, being constructed solely of plant material, indicate that the environment in which the caddisfly larvae lived was a calm, shallow-water, well-oxygenated environment.

Potter and Dilcher (1980) studied palynomorphs, megafossil material (leaves, fruits, seeds, and flowers), and the geomorphology of middle Eocene-aged clay lenses at approximately 25 localities in western Kentucky and Tennessee. They concluded that these elongated clay lenses represent clay plugs in oxbow lakes which formed on an ancient flood plain. The oxbow lakes resulted from the meandering of the "Appalachian" River system as it entered the low-lying Mississippi Embayment in western Kentucky and built a poorly defined delta in northern Mississippi. Potter and Dilcher (1980) also stated that these clay lenses represent time intervals of approximately 500 to 1500 years.

Much more work needs to be done on the geology and paleontology of the Bolden Pit. A detailed study of the geology should delineate the contact between the Tallahatta and the Kosciusko formations, identify depositional environments, and may explain the source of the siltstone layer. Additional paleontological studies of the fauna, flora, and trace fossils will determine paleoclimate and assist in interpreting depositional environments. The close association of faunal and floral elements may give additional insight into the coevolution of insects and plants. Many of the insects from the Bolden Pit have never been reported from Eocene sediments of the southeastern United States, and the spiders are the oldest ever recovered from the Tertiary System in Mississippi. Therefore, the Bolden Pit may yield many more specimens, both faunal and floral, that have yet to be described.

ACKNOWLEDGMENTS

I wish to thank Holly Springs Brick and Tile Company for allowing me to collect from this unique locality. I also want to thank Mike Fenster for realizing the importance of the site, for helping to collect truckloads of samples, and for finding the first ant wing. I want to thank Susan Bowen and Phillip Weathersby, who spent many hours in the pit splitting rocks under a blazing Mississippi sun. I also want to thank Dr. William B. Size, of Emory University, for use of equipment to photograph the smaller specimens; Sam Johnston for use of additional photographic equipment; Dr. Patricia H. Kelley of the University of North Dakota, Carl Froede, Jr., Jack Cowart, and Diane Scott, who critically read the manuscript and provided comments; and Carl Froede, Jr., and Anne Marie Gillespie for providing reference material.

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OBITUARIES

NORMAN FREDERICK SOHL
July 14, 1924 - April 14, 1993

Norman F. Sohl contributed greatly to the understanding of Mississippi's Cretaceous stratigraphy and gastropod faunas. He published revisions and additions to the Maastrichtian gastropods of the Mississippi Embayment's Ripley, Prairie Bluff, and Owl Creek formations and was first to publish the Campanian gastropods of the Coffee Sand. Norm worked 39 years with the U. S. Geological Survey before his retirement on April 3, 1993. His retirement party was on April 7, only a week before his death.

Norm was born in Oak Park, Illinois, to Florence Wray and Fred John Sohl. He attended elementary school in Forest Park and high school in Sycamore, Illinois. In 1943, he was drafted into the Army and sent to Europe with a rifle company in the First Infantry Division. Norm landed on Omaha Beach in Normandy on D-Day and fought in France, Belgium, and Germany. He won the Bronze Star for his actions during the battle of Aachen.

Norm entered the University of Illinois in 1946 and married Dorothy M. Jansen of Sycamore, Illinois, on June 5, 1947. He completed his B.S. in geology from the university in 1949. Norm begin his graduate work at the University of Illinois and selected for his thesis topic the Late Cretaceous gastropods of Mississippi and Tennessee. He later followed his major professor, Bernhard Kummel, to Harvard University where he completed his Ph.D. in 1954. At this time, he accepted a position with the Paleontology and Stratigraphy Branch of the U. S. Geological Survey. Norm served as Chief of the Paleontology and Stratigraphy Branch from 1968-1973 and as Chairman of the Geologic Names Committee from 1977-1981. He was recipient of the Paleontological Society Medal for 1991. The newly published Mississippi Office of Geology Bulletin 129 on the gastropods of the Coffee Sand is dedicated to Norm. It contains a brief autobiography written by Norm in 1991 at the request of the Memphis Pink Palace Museum.

VICTOR AUGUST ZULLO
July 24, 1936 - July 16, 1993

Victor A. Zullo, Professor of Geology at the University of North Carolina at Wilmington and President of the Carolina Geological Society, passed away unexpectedly early in the morning on July 16, 1993. Vic had strong interests in the geology of the Gulf and Atlantic coastal plains. His expertise was in fossil barnacles and their biostratigraphic utility. Vic published two articles on this subject in *Mississippi Geology*, one on a turtle barnacle from the Vicksburg Group (March 1982) and another on a new species of *Balanus* from the Chickasawhay Limestone (September 1982). Besides his work on barnacles, Vic and others in the Department of Earth Sciences at U.N.C. at Wilmington organized the Bald Head Island Conference on Coastal Plains Geology. Three conferences have been held to date, all of which have provided constructive gatherings of coastal plain geologists and paleontologists in a relaxed island/beach setting.

Vic was born in San Francisco, California, and attended the University of California at Berkeley, where he earned bachelor, master, and doctoral degrees. While there, he studied under Professor J. Wyatt Durham on the classification and phylogeny of the Balanomorpha but also developed interests in mollusks and echinoids. Upon graduation, Vic spent his early professional years at the Marine Biological Laboratory at Woods Hole, Massachusetts, the Department of Paleontology at the California Academy of Sciences in San Francisco, and as a lecturer at San Francisco State University and the University of California at Berkeley. In 1971, he joined the University of North Carolina at Wilmington as Director of the Program in Marine Studies and a Professor of Biology, and later as a Professor of Geology in the Department of Earth Sciences. In addition to his interests in Cirripedia, Echinoidea, and Mollusca, Vic developed interests in the geology, tectonic history, and geomorphology of the Atlantic and Gulf Coastal Plains, and later in sequence stratigraphy. (This notice is slightly modified from a memorial to Vic Zullo read to the November 1993 meeting of the Carolina Geological Society by W. Burleigh Harris.)

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