GENESIS AND MORPHOLOGY OF MOUNDED SOILS

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NOMENCLATURE

Crotovinas, also Krotovinas (Common in Russian literature) refer to translocated soil in tubular streaks within soil horizons. Their presence are generally credited to rodents (Joffe (36), Brewer (14)).

Glossic Tongues consist of bleached soil coming from a light colored albic horizon which generally lies immediately above the subsoil (Soil Classification USDA 1960).

Argillic horizon is the eluviated clay accumulation in the illuviated horizon (Soil Classification USDA 1960).

Mollic epipedon is a dark colored horizon generally comprising the surface horizon, a characteristic associated with the highly fertile grassland soils. A detailed description is given in the section on soil classification also in Soil Classification USDA 1967 and later.

Pedon is a three dimension body of soil large enough to allow a study of the true nature of any horizon represented in the particular soil (Soil Classification USDA 1960).

Thermic is soil temperature within a range of 15° to 22°C occurring at depths of 50 cm or at the depth of rock (Soil Classification USDA 1960).

CHAPTER I

INTRODUCTION

A vast area of land comprising parts of Missouri, Kansas, Oklahoma, Texas and Louisiana is dotted intermittently with small slightly domed oval shaped mounds. In size they average about 15 meters in diameter and less than one meter in height. Common densities range between one and four thousand to the square mile. Similar areas are found in California, Washington, Oregon, Wyoming, Colorado, Idaho, South Dakota, Minnesota and in many other parts of the world. Fenneman (26) referred to these mounds as "pimpled plains," Nikiforoff (57) "Hogwallows," "Micro relief"; and Scheffer (76) "Mima mounds". These mounds have long been a curiosity to observers. Many hypotheses have suggested their origin with none widely accepted. Veatch (89) citing hypotheses of origin included human, ants, burrowing animals, flood currents, gradual erosion, spring or aqueous volcanoes due to artesian pressure, gas vents, eruption from uneven pressures of wet clay and sand, low dunes and root wads.

Branner (10) suggested mounds were remains of fish nests. Mud lumps, large concretions and the polygonal clay shrinkage erosion pattern were evaluated by Melton (50). Pewe (65) and Newcomb (56) favored a glacial or preglacial origin. Pewe (62) observed mounds in Alaska and ascribed the phenomenon occurred from ice wedges in cracks bulging the centers of polygons. Joffe (36) accounted for formation of mounds in the Arctic region resulting from liquid mud eruptions and soil blisters due to ice. Dalquest and Scheffer (20) concluded the mounds of Thurston County, Washington were built by the pocket gopher (Thomomys talpoides). This hypothesis has been supported by Koons (39); Price (64, 65): Arkley and Brown (2), and has been advanced to the areas of the pocket gopher Geomys. Scheffer (77) in a monograph concluded that other fossorial rodents as well as gophers may build mounds on thin or poorly drained soils. Breckenridge and Tester (12) suggested the Manitoba toads (Bufo hemiophrys) be considered in the origin of the mounds.

There are perhaps several kinds of mounds stemming from various origins. The type of mound considered in this report is shown in (Figure 1).

This paper contains information on mounded soils in relation to climate, vegetation, biological activity and presents an hypothesis for the origin of the mounds.

In the study the search for the origin of the mounds is secondary to determining the true nature of soil pedons associated in and adjacent to the mounds. The report emphasizes special soil characteristics associated in the mounds and compares these features to soils of the interspace. Mounded soils and soils of the associated interspace are classified according to differentia criteria of the 7th Approximation, the classification system currently in use, developed by the Soil Survey Staff USDA (85).

Over a million acres of land containing mounds in Eastern Oklahoma are in areas of soil survey programs. The associated soils have not been extensively investigated.

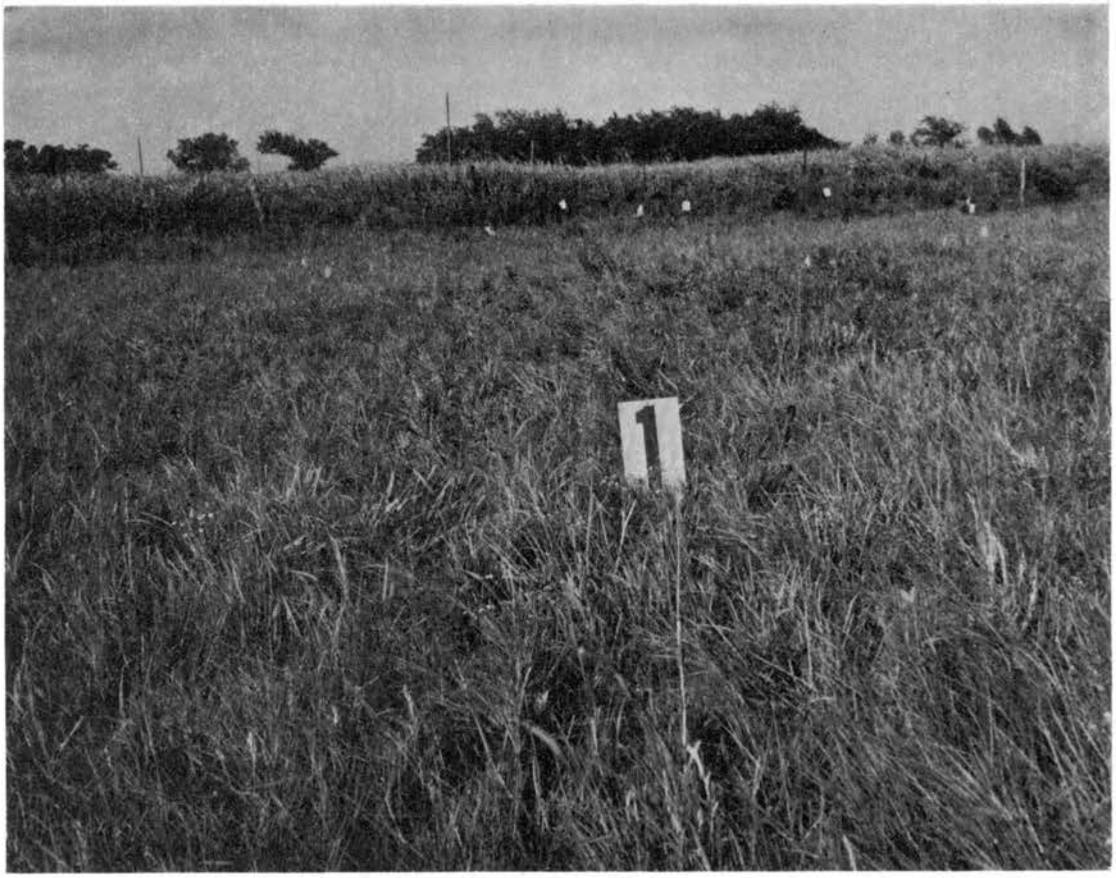


Figure 1. Mound excavated in Site I of this study.

Special attributes of mounded soils may accommodate more specialized cropping than the associated intermound should there be a demand. The peculiar uniform spacing pattern of the mounds in a landscape may conveniently be exploited for a favorable use as a fruit or truck crop area. Some of the superior attributes of the mounded soils recorded in this report may, with some knowledge of their origin, be implemented in other soils for improvement or restriction of degradation.

Major Area of Study

The study was conducted primarily in an area extending between 10 and 40 kilometers north of Eufaula. The area comprises a southern part of Muskogee and a northern part of McIntosh counties Oklahoma. Knechtel (38) placed the present stage of geomorphic development of the associated region to be no older than late Pleistocene. Rocks that underlie the sites are of the Pennsylvanian geological system. These rocks are interbedded gray silty to sandy shales, siltstone, brown limestone and medium grained sandstone (Meeks (47), Neff (54)). Associated soils are of the Taloka, Parson, Dennis, Bates, Collinsville, Talihina, Okemah, Choteau series (Gray and Galloway (31)). Dominant slopes associated with the mounds in the area are nearly level to gently sloping. The general slope is northeastward. Associated elevation is about 180 meters above sea level. The climate is a temperate, continental, moist, subhumid type. Climatic data for Eufaula, summarized in the records of the U. S. Weather Bureau, list the annual mean precipitation as 105.51cm with the mean annual temperature as 16.6°C.

Tall grass prairies comprise the study areas. Forested landscapes bordering local streams and on rough broken upland lie within a short distance.

A mound in a 3.25ha native meadow located in the northeast quarter of section 31, t. 13 N., R. 17 E. Muskogee County, Oklahoma was used as the nucleus of the study (Figure 2). Site I encompasses the mound with side dimensions of thirty meters. The 3.25ha meadow contained 46 mounds having a similar size and appearance. Other areas containing mounds were examined and compared with the mound of Site I.

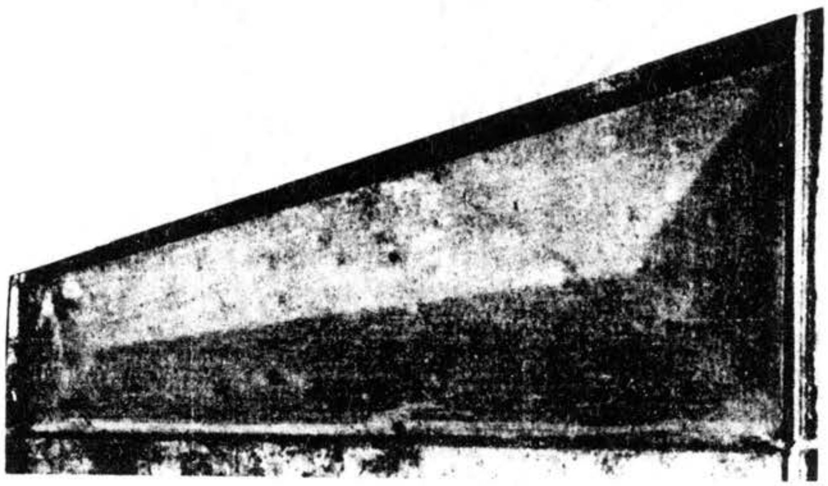


Figure 2. Aerial photograph of the 3.25 ha meadow in which the major part of the study was conducted.

CHAPTER II

REVIEW OF LITERATURE

Man and the Mounds

The possibility of man constructing mounds has long been pondered. Scholars researched history over a century past for the existence of mound builder tribes. President William Henry Harrison once wrote, "They were a numerous people". Controversy that raged caused congress in 1881 to provide a special allocation to study the mysterious domes. This investigation did remove some myths. Some effigies were pronounced fakes as related in the Bureau of Ethnology's Twelfth Annual Report and other facts unveiled showed no single race of people was responsible for the occurrence of the mound (Silverberges (82)).

Resulting from early postulation of massive migrations of man to the Southwest, mounds are often grouped together by those speculating a human origin. Artifacts of early man have been unearthed mostly in association with large mounds that are also termed tumuli. Spiro mounds of Oklahoma; Miamisburg, Ohio mounds; Grove Creek mounds of Virginia; Etowah Tomlin group in Georgia; Kings mounds in Kentucky; and Cahokia group in Illinois are sites obviously occupied by early man. These mounds are not numerous and generally have gigantic measurements in comparison to the small mounds of the prairies which occur in densities of several thousand to the square mile. LeConte (42) referred to these mounds as "Prairie mounds and Hog-wallows." Fenneman (26) referred to these as "pimpled plains." Scheffer (76) referred to them as the "Mima mounds". Melton (50) referred to them as "natural mounds" and concluded densities were too great to be contributed by an human population that was known to exist.

Ants and the Origin of the "Natural Mounds"

The hypothesis, by Hilgard (33), credited ants with the construction of the mounds. Based on observations made during a reconnaissance of Louisiana in 1869, he concluded that the only reasonable explanation of the origin of the mounds in Louisiana was due to the work of ants. In his summation he raised the question as to how the once teaming population of the area came to be removed. Climate could not be considered because ant hills built by the "Atta" leaf cutting ants are now found in parts of Texas. Veatch (89) quoted Mr. E. A. Schwarz of the National Museum, reporting that Atta ant hills in Cuba reach a height of 3 to 3.5 meters with a lateral diameter several times greater. This is in contrast to ant hills in Texas, reported by Dr. W. M. Weeler, which reach a height of 31 to 62 cm. Veatch (89) reports the "white ants" (termites) of South America, Africa and Australia build mounds consisting of mud mixed with vegetable matter which upon decay could well give rise to the high porosity found in the mound soils of the Gulf region. The ant Termes bellicosus prefers soils of a clay texture to use for their building material. However, in Africa studies show ant-made structures have long axes pointing north and south so enabling more radiation of the sun to keep the walls dry.

Ants are selective in materials used in their structures. This variation of materials is not known in the mounds in Eastern Oklahoma,

(Figure 3).

Figure 3. Ant structures examined in Eastern Oklahoma consist mostly of iron and manganese concretions.

Fish Nest Mounds

Branner (10) discussed the Pacific Coast mounds and listed the fish nest hypothesis. Bik (9) in a geological survey of Canada, Ottawa, Ontario reported shell fragments in mounds. Bernard (8) concluded that colonies of crabs probably constructed the mounds in the Colorado Matagarda Delta. Arkley (1) reported the shovel-nosed sharks have been suggested to be responsible for the construction of mounds when the land was submerged. Branson (11) concluded that all mounds are on geological deposits no older than late Pleistocene. No inundations have occurred in Eastern Oklahoma within this period of geological time.

Ice and Glacial Agencies and Mounds

Newcomb (55) reports that the "Mima mounds", Thurston County Region, Washington, must have been derived from glacial forces. These mounds are described as containing black silt, sand, and pebbly gravel. The material is friable loose and lacking in clay or plastic constituents. He does not give a depth for the soil. He also reports that the black silt contains pebbles to a maximum of 3.8cm in diameter. The silt of the mounds is essentially the same in composition, texture, and structure as the soils that mantle the area. Sizes of the "Mima mounds" range from less than 1 to about 2.5 meters in height.

The frost polygons of the Arctic are found in marsh areas where soil is subject to freezing and thawing. Pewe (62) described mounds in the Fairbanks, Alaska area. He described the Alaska mounds varying in diameter from about 3 to 9 meters and less than 1 to about 2.5 meters in height. He concluded that these mounds were formed from the melting of a network of ice wedges in the ground. When the network of ice wedges lie in a polygonal network pattern, the ground in the center of the ice network is left standing to form mounds. Bik (9) reported references stating mounds in Canada to have diameters of 460 meters. He reported measurements of 185m in diameter and 9m high. Hubbs (35) suggests the sizes of mounds diminish toward the equator. Joffe (36) discusses entrapment of frozen water which exerts a pressure to raise mounds like gigantic blisters in the Tundra region. Some of these mounds were reported to be more than 6 meters high, all being full of ice or water, and where the water escapes, large caverns occur. Liquid mud erupting to the surface forms another type of mound in the Arctic regions. Newcomb (56) and Ritchie (71) relate a condition of extreme washing between ice remnants which left a soil standing to form mounds. These hypotheses have merit for the Arctic region and perhaps for some areas affected by the Pleistocene glaciers but is not thought to have any significance for the many areas containing mounds in the non-glaciated regions of the United States (Melton, (50)).

Spring and Gas Vents

Veatch (88) mentioned the hypothesis that gas vents were responsible for the development of the "Natural mounds". This idea was prompted by the large amount of vegetation buried in the coastal plains strata which may have produced gases with associated artesian water, which upon eruption to the surface, leaves low fine sand cones. As he pointed out, there are places on the coastal plains where these small sandy cones have developed, namely, near Sulphur City, Louisiana and near Teneha in Northeast Texas. Shepher (81) described low spring cones in Southern Missouri. Veatch reported the eruptions of gas and water, or water alone which produced small mounds in the area of the New Madrid earthquake of 1811-12.

Hydrostatic Pressure Eruptions

Nikiforoff (57) theorized that mounds were formed by hydrostatic pressures coming from lower soil horizons, pushing soil to the surface through "windows" in "hardpan" soils. Retzer (69) studied soils associated with mounds in San Joaquin Valley, California and determined the possible mode of origin came from subsurface mud flow. Arkley and

Brown (2) ruled this theory out of their California study because no vents existed through the "hardpan" soils under the mounds which they studied.

Wind Erosion - Dune Hypotheses

A wind origin was suggested for mounds by Featherman in 1872 (25). His hypothesis favored a whirlwind deposit. Clendenis in 1896 (17) favored a dune deposit for the origin of the mounds. Veatch (88) discussed the possibility of the mounds being formed by wind. Shaw (79) credited wind transportation and deposition. The dune hypothesis is based on the resemblance of these "Natural mounds" to the low dunes which have been formed in arid regions of the West around clumps of bush vegetation. Such similarity is among mounds adjacent to the Pecos River in Southwestern Texas. Veatch (88) reported that Hayes concluded that the mounds of Southeastern Texas were deposited by wind after comparing them to low mounds, clearly due to wind action, 25 to 35 km southwest of Green River City, Wyoming. G. K. Gilbert furnished pictures for Veatch's report on these low circular dunes found in White Valley, Western Utah. Barnes (5) studied the mounds near San Diego, California and believed shrubs caused development of mounds with the action of wind and water.

Malde (44), (45) described mounds in the Western Snake River Plain, Idaho as being surrounded with pavement and many tabular stones consisting of basalt rock. LeConte (42) compared similar mounds of Washington and Oregon. Bretz (13) and Freeman (28) referred to the mounds in Washington as scabland mounds. Freeman reported crops flourish on the mounds. He contended these mounds were found only where pits occur in the basalt. The mounds were hypothesized to have formed by accumulation of soil blown into the pits. Vegetation growing retained wind blown material which formed the mound. Olmsted (58) gave a similar conclusion of these mounds on the Columbia Lava Plateau but pointed out that Waters and Flagler (92) studied the basalt surface and denied the depressions existed. Piper (63) concluded that these mounds were decaying basalt caps. These caps were left when flowing water wore away less stable surrounding rock.

Water Erosion Hypothesis

In a geological survey of LeFlore County, Oklahoma, Knechtel (37) describes mounds in general as ranging from 31 to 91cm high and about 15 meters in diameter. They occur with a density of 4,000 to an area of 1.609 square kilometers. They are found on silty soil, and some soils contain small pebbles composed of limonite. The soil at the base of the "Natural mounds" rests abruptly on a subhorizon that is nearly level and consists of soil that is firmer and lighter in color than that composing the mounds.

Knechtel believed that the mounds were formed since the region attained essentially its present stage of geomorphic development which would place their age no older than late Pleistocene. He favored the views of Melton (48), believing the mounds to be the result of a network of small streams. Krinitzsky (40), Waters and Flagler (92), Holdredge and Wood (34) concluded from their research that water erosion or action of small meandering streams developed the mounds.

Krinitzsky (40) theorized that the mounds were formed from ripple action of flowing water. Gangmark (29) theorized the mounds were formed by variations of velocities of floodwaters with downstream areas sheltered by vegetation forming mounds. The water erosion hypothesis was ruled out by Arkley and Brown (2) because it didn't explain the related, similar dome shape of the many small "Natural mounds".

Clay Shrinkage -- Polygon System

Purdue (68) observed the "Natural mounds" in Arkansas and attributed ground water action on the clayey sublayers to their development. Here the clayey textured subsoil was saturated with water during wet seasons. He was confident that the question would be answered as to origin by studying the climatic conditions where the mounds occur. Knechtel (38) had a similar hypothesis as to the origin of the mounds, suggesting it to be related to a shrinkage -- polygon system. This, he suggests, is related to cracks in the underlying claypan. At first the cracks were everywhere, then as they were gradually widened by erosion the corners of the blocks were rounded and, as a result, a new mound was formed.

Hallsworth et. al., (32) described the gilgai soils in Australia in which small rounded "puffs" have formed at intervals in the clayey soils. The optimum development was associated with the swelling capacity of clay. Bellis (7) described the tropical black clays of Kenya to contain mounds 15 to 30 cm in height and 18 to 46 cm in diameter. Washburn (91) compared similar occurrences in the Polar region with some having an accumulation of gravel and rock sorted in some areas along the borders in a polygon manner. Roscoe (73) reported large nonsorted polygons on steep slopes in the Antarctic. Scheffer (76), describing the mounds in the prairies of Western Washington, mentioned hollows between the mounds are filled with cobblestones up to the size of a football.

Mud Lump Hypothesis

Along the lower part of the Mississippi River mud lumps have been deposited by water. These mud lumps form small mounds on the flood plains. Mud lumps have a special structure. Soil high in clay is rolled into a ball that has an arrangement of "onion skin". Melton (50) disposes of this hypothesis because no similar structure is noted in the many mounds in Louisiana and Texas.

Uprooting of Trees

The hypothesis that the "Natural mounds" were formed by the uprooting of trees was suggested by Farnsworth (24). He made the supposition that the large mass of soil would be left to form the mound after the tree decayed. This hypothesis loses support by Melton (50) because of the large size of the mounds and the lack of evidence of tree growth in many areas containing mounds.

Large Concretions

Spellmon (83) observed the "Natural mounds" of Missouri and concluded their origin came from the decay of great subcarboniferous limestone concretions. His observations were made in Southwestern Missouri. He theorized that the large lime concretions contained flint which by being more resistant to weathering was left in place to form the mound gradually. According to his report, some fragments of flint stones were found in the mounds of that region. One interesting feature he reported was that the mounds were more productive than the intermound areas. Corn, if planted for a first crop after the land was cleared, would be twice as tall as on the intermound areas. Branner (10) also attributed the development of mounds to lime concretions. Analyses of mounded and intermound soils by Prof. C. A. Merritt, University of Oklahoma, showed no apparent difference between the two areas. Both samples were low in lime (Melton (50)).

Natural Mounds and Pocket Gophers (Family Geomyidae)

Dalquest and Scheffer (20) attributed the origin of mounds on the Mima Prairies, Thurston County, Washington to the pocket gopher Thomomys. Scheffer (76) used the name "Mima mounds" in referring to this type of mound in various areas of the United States. In studying the "Natural mounds" of Louisiana, Koons (39) gave credit of development to the pocket gopher Geomys. Price (64) also supported the gopher hypothesis. Arkley and Brown (2) concluded, after a lengthy study of mounds in certain parts of California, that the pocket gophers are undoubtedly the builders of the mounds. Melton (50) ruled out the gopher hypothesis on the basis that it would require a concerted action of a large number of burrowing animals to build the mounds and that concerted work is insufficient to produce the mounds today. Newcomb (56), objecting to the gopher hypotheses, described observance of the rodents flattening the mounds on the Rock Prairie region of Washington and cited Nikiforoff (57) observed ground squirrel degrading mounds of the Great Valley of California. Scheffer (76) pointed out that pocket gophers were not in the Mima Prairies, but that this area contained evidence of having been occupied by them previously.

Manitoba Toads and the Mounds

Breckenridge and Tester (12) found in studying the Manitoba toad *Bufo hemiophrys* that the mounds were used in hibernation. The number of toads that was found to utilize a mound in this location of Minnesota was 225 and leads to the suggestion they be considered in the origin of the mounds. Tester and Breckenridge (86) in a later study reported numbers occupying 5 mounds in the winter of 1962 was 2,324. Less than one percent of the number came from the associated intermound area.

Geography of the Study Areas

The field study of mounds was conducted in the southwestern part of Muskogee County and the northern part of McIntosh County which is in the eastern part of Oklahoma. The elevation varies between 150 and 200 meters above sea level.

Relief

Common slopes associated with landscapes containing mounds range from nearly level to gently sloping. Occasionally landscapes with slopes greater than 5 percent are found containing mounds.

The slopes of Site I are nearly level. Runoff is medium to slow with no discernible drainage pattern.

Geology

Rocks that lie below the regolith in the landscape of Site I are of the Boggy unit of the Des Moines series of the Pennsylvanian geological system. The Boggy formation averages about 500 feet thick in the general area. It consists of medium grained, tan to brownish sandstone, siltstone and gray to dark gray shale (Meeks (47), Neff (54), Bell (6)). Shale was encountered beneath the soil solum of Site I.

Climate

A temperate, continental, moist, subhumid type of climate prevails in the area where the mounded soils were studied. The mean annual precipitation is 105.51 cm with a mean annual temperature of 16.6^{o}C. The spring months are the wettest season (Table I).

The mounds in Oklahoma are closely associated with the 101.6 cm plus rainfall belt. The soils of the intermound areas of Site I are saturated with water at some season during the year. As indicated by the degree of soil mottling, the mounded soils are not commonly saturated in the upper fringes of the mollic epipedon. The Thornthwaite annual P-E index is about 68 for the location.

Plants

Soils occurring in the study area developed under a cover of herbaceous plants consisting mostly of tall grasses. The small upland streams that form the drainage system of the upland prairies are generally surrounded by trees. Rough broken areas that lie within 5 to 10 kilometers are also forested. The forest consists mostly of deciduous trees. In the local region mounds occur primarily under prairie type vegetation. Invasion of trees occurs on a few border areas. Vegetation measurements were made of Site I which showed greater production on the mound than on the intermound.

TABLE I

EUFAULA AVERAGE MONTHLY PRECIPITATION AND TEMPERATURE 1887-1968

		mm	C°
Jan.		60.2	4.5
Feb.		57.9	7.2
Mar.		75.2	10.7
Apr.		120.1	16.3
May		152.7	20.7
June		100.1	25.2
July		86.4	27.8
Aug.		93.2	27.8
Sept.		89.5	23.6
Oct.		84.6	17.7
Nov.		68.7	11.1
Dec.		66.5	6.2
	Average Annual	1055.1 mm	16.6°C
		105.51 cm	

Time

Time pertaining to soil weathering in the mound and intermound is considered a constant factor. Knechtel (38) placed the age of the surface containing mounds in the associated region to be no older than late Pleistocene.

CHAPTER III

PROCEDURES OF THE STUDY

Procedures of the Field Study

Literature pertaining to mounds was reviewed and compared to the areas studied in the field.

Mound distribution in Oklahoma was studied by use of aerial photographs, Published Soil Survey Reports, literature review and the assistance of Soil Scientists who worked in the various areas. Distribution of mounds was plotted on climatography maps of Oklahoma (recorded 1960 U.S. Weather Bureau). Mounds sampled were in an area extending between 10 and 40 kilometers north of Eufaula in Muskogee and McIntosh Counties Oklahoma. The area selected for the nucleus of the study was in consideration of its well managed condition and its representation of the type of soil and landscape associated with mounds. Past management used the 3.25ha native meadow elected for the study for hay production with no records of fertilizer applications in the past 25 years.

The location of the meadow is in the southwestern part of Muskogee County, Oklahoma in the Northeast one fourth of the Northeast quarter of Section 31, T. 13N., R.17E.

Elevations and locations of the 46 mounds in the 3.25ha meadow were surveyed by using a transit. Backhoe equipment was employed in making excavations (Figure 4).

Figure 4. Backhoe equipment used in making excavation of Site I.

The mound of Site I was excavated with a primary entrenchment of a 90 degree direction from true north and a secondary entrenchment in a 180 degree direction from true north. The secondary excavation did not intercept the north wall of the primary excavation. The depth of the excavation was 220 cm. For comparison an intermound excavation was made to a similar depth located 15 meters at 270 degrees from true north from the center of the mound. Reference numbers were placed at intervals of 1.5 meters throughout the excavations. Zero marked the intermound excavation with numbers one through nine located in the mound. Location three was located in about the center of the mound (Figure 5).

Using a transit, a profile survey compared the position of soil horizons and special features in the mounded soils to the intermound soils.

Percentages of worm casts were determined by measuring exposures intercepting a vertical transect. Nine soil pedons were described in the mound and one in the intermound. Samples were collected from representative pedons numbered 0 and 3. Bulk density samples were taken with a 68.75 cc volume core sampler. Bulk density samples were taken in soil horizons of pedons numbers 0 and 3 in Site I; other bulk density samples were taken in triplicate at a depth of 23 cm in 9 different mounds and associated intermounds of five different landscapes. Vegetation was measured by a random method. Vegetation in 9 square meters from four mounds and four associated interspaces was clipped and air dried to determine average forage weights. Quadrats clipped were alternated on three transect lines extending across the site.

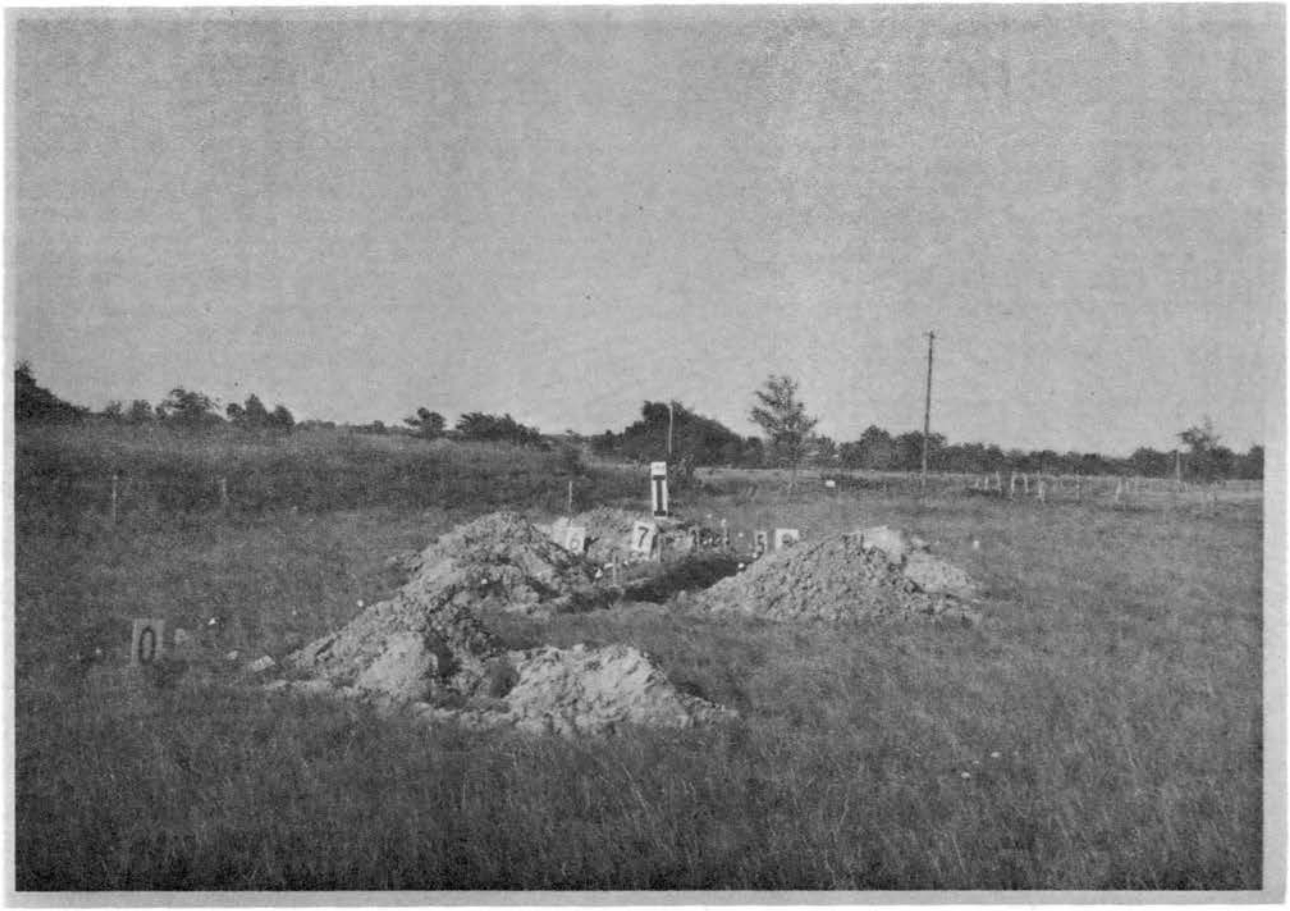


Figure 5. Excavations of the mound and intermound of Site I. 0 represents the intermound pedon and 1 through 9 represents pedons in the mound.

Vegetation composition percentages were determined by transects of four different mounds and equal area of interspace. Plants counted were those nearest each meter marking on the measuring tapes stretched across the site locations. The selected transects were positioned 1.5 meters apart across the selected mound and interspace.

Laboratory Methods and Procedures

Soil samples for chemical, mineralogical and physical analysis were air dried and processed to pass a 2 mm screen. Mechanical analyses were determined by procedures outlined by Day (22). The pH of the soil was determined on a 1:1 soil-water paste and on a 1:1 soil-Kcl mixture using a Corning pH meter. Exchangeable sodium, potassium, calcium and magnesium were determined by leaching a soil sample with neutral IN ammonium acetate. Sodium and potassium were determined with a Perkin-Elmer #303 atomic absorption spectrophotometer. Calcium and magnesium were determined by the EDTA method (84). Soil organic matter was determined by the potassium dichromate wet combustion method of Schollenberger (78). Exchangeable hydrogen was determined by the barium chloride-triethanolamine method of Peech, et al. (61). Total phosphorus determinations were made by digestion of the soil with perchloric (72%) acid according to the Shelton and Harper procedure (80).

The molybdemeous blue color was developed by using the ascorbic acid reduction procedure. Bulk density samples were oven dried and bulk density determinations were made in the laboratory (84).

CHAPTER IV

LOCATIONS OF SITES CONTAINING MOUNDED SOILS AND DESCRIPTIONS OF SOIL PEDONS

Locations of mounded Soils in Muskogee and McIntosh Counties Oklahoma

Pedons described are representative of the soils associated with mounds in the general area of the study. Site I, which was the nucleus of the study, has slopes of less than 1 percent. Other landscapes similar to Site I are located as follows:

Site I - Located in NE^4, NE^4, NE^4 Sec. 31, T. 13N., R. 17E, Muskogee County, Oklahoma
NE^4, NE^4 Sec. 5, T. 12N., R. 17E. McIntosh County, Oklahoma

Soils occurring in this type of landscape include Taloka & Parson soil series.

These sites represent soils associated with mounds on landscapes ranging from 1 to 5 percent slopes. The site, designated as Site II is representative of soils and mounds associated with this type of landscape. Sites containing this similar landscape and soils are as follows:

Site II - Located in SW^4 NE^4 Sec. 27, T.12N., R.17E. McIntosh County, Oklahoma
N^2 NE^4, NW^4, Sec. 29, T.12N. R.17E. McIntosh County, Oklahoma
E^2, NE, NW^4, Sec. 27, T.12N., R.16E. McIntosh County, Oklahoma

Soils associated with landscapes similar to site II include Dennis, Bonhom, Choteau, and Okemah soil series.

Site III represents soils associated with shallow depths to sandstone or shale. In Site III slopes were 1 to 12 percent range with the rapid drop resulting from an abrupt grade on the east side of the site to the valley below. This type of site is associated with the upper rims of the valleys. Representative sites are as follows:

Site III - is located 320 meters east and 8 meters south of the northwest corner Sec. 27, T.13N., R.16E. Soils occurring in this type of landscape include Collinsville and Bates soil series.

Pedon Description

Site I - Intermound Soil Pedon No. 0

(Colors are for moist soil unless otherwise stated).

A11 - 0 to 9 inches (0-19 cm), very dark grayish brown (10YR 3/2)silt loam; grayish brown (10YR 5/2); weak fine granular structure; friable when moist; few distinct dark brown mottles; abundant fibrous roots; porous; common worm casts; pH 5.5; gradual boundary.

A12 - 9 to 18 inches (23-46 cm), dark grayish brown (10YR 4.5/2) silt loam; light brownish gray (10YR 6/2) when dry; weak fine granular structure; friable when moist; common fine distinct reddish brown (5YR 4/3) mottles; common worm casts; many fibrous root; pH 5.5; smooth clear boundary

A21 - 18 to 26 inches (46-66 cm), brown (10YR 5/3) loam; very pale brown (10YR 7/3) when dry; weak medium granular structure; friable; many fine distinct yellowish brown mottles; few fine hard and soft brown concretions; few worm casts; pH 5.0; gradual boundary.

A22cn - 26 to 31 inches (66-79 cm), light brownish gray (10YR 6/2) silt loam; light gray (10YR 7/2) when dry; moderate medium granular structure; friable when moist; many fine distinct strong brown (7.5YR 5/6) mottles; many soft and hard, fine and medium concretions; porous; few fine roots; few worm casts; pH 5.0; smooth abrupt boundary.

B21tcn - 31 to 43 inches (79-109 cm), grayish brown (10YR 5/2) silty clay loam; light brownish gray (10YR 6/2) when dry; moderate medium blocky structure; very firm when moist; thin continuous clay films on ped faces; common medium distinct strong brown

(7.5YR 5/6) and a few fine distinct red (2.5YR 4/8) mottles; common hard brown and black concretions; pH 6.0; gradual boundary.

B22tcn - 43 to 55 inches (109-140 cm), grayish brown (10YR 5/2) silty clay loam; light brownish gray (10YR 6/2) when dry; moderate medium blocky structure; very firm when moist; thin continuous clay films on ped faces; common medium distinct strong brown (7.5YR 5/6) and few fine red (2.5YR 4/8) mottles; few fine and medium concretions in soil mass; many in pockets of pale brown clay loam textured soils; pH 6.0; gradual boundary.

B3cn - 55 to 71 inches (140-180 cm), brown (10YR 5/3) crushed gray (10YR 6/1) with fine dark gray and fine distinct yellowish red (5YR 5/6) mottles; silty clay; many, fine and medium, soft and hard, brown and black concretions in broad areas and pockets; pockets contain lighter textured lenses of light brown soil; weak very fine blocky structure; firm when moist; roots rare; pH 7.5; gradual boundary.

C - 71 to 80 inches + (180-203 cm+), brown (10YR 5/3) gray (10YR 6/1) silty clay loam; pH 8.0

Pedon Description

Site I - Mounded Soil Pedon No. 3

(Colors are for moist soil unless otherwise stated).

A11 - 0 to 19 inches (0-48 cm.), very dark grayish brown (10YR 3/2) silt loam; grayish brown (10YR 5/2) when dry; weak fine granular structure; friable when moist; fibrous roots abundant; porous; many fine channels and worm casts; numerous crotovinas 6 to 18 cm in diameter; pH 5.5; gradual boundary.

A12 - 19 to 29 inches (48-77 cm), dark grayish brown (10YR 3.5/2) silt loam; grayish brown (10YR 5/2) when dry; medium fine granular structure; friable when moist; few, fine, distinct dark brown (7.5YR 4/4) mottles; many fibrous roots; porous; many fine channels and worm casts (color of some casts lighter than surrounding soil); numerous crotovinas 6 to 18 in diameter; pH 5.5; gradual boundary.

A21 - 29 to 36 inches (77-91 cm), dark brown (10YR 3.5/3) silt loam; brown (10YR 5/3) when dry; medium fine granular structure; friable when moist; few fine distinct, dark brown (7.5YR 4/4) mottles; many fibrous roots; porous; many fine channels and worm casts (color of some casts darker than surrounding soil); crotovinas 5 to 10 cm; pH 5.2; gradual boundary.

A22 - 36 to 40 (91-102 cm), dark brown (10YR 4/3) silt loam; brown (10YR 5.5/3) when dry; weak fine granular structure; friable when moist; few fine distinct dark brown (7.5YR 4/4) mottles;

few fibrous roots; porous; few fine concretions; many channels and worm casts (colors of some casts darker than surrounding soil); crotovinas 10 x 15 cm; pH 5.0; gradual boundary.

A23cn - 40 to 47 inches (102-119 cm), yellowish brown (10YR 5/4) silt; very pale brown (10YR 7/4) when dry; weak, fine, granular structure; friable when moist; common fine and medium, distinct dark brown (&.5YR 4/4) mottles; many, fine and medium, soft and hard, yellowish brown and very dark gray concretions; porous; many worm casts; few fibrous roots; pH 6.0; roots; clear smooth boundary.

B21tcn - 47 to 54 inches (119-137 cm), yellowish brown (10YR 5/4) heavy silt loam; very pale brown (10YR 7/4) when moist; moderate fine blocky sturcture; very firm when moist; common fine distinct yellowish brown (10YR 5/6) mottles; many fine and medium brown and black concretions; few roots; pH 6.0; gradual boundary.

B22t - 54 to 68 inches (137-173 cm), composed of colors, yellowish brown (10YR 5/4), grayish brown (10YR 5/2) and specks of reddish brown (5YR 4/4); silty clay loam; light brownish gray (10YR 6/2) when dry; weak, medium subangular blocky structure; very firm when moist; thin continuous clay films on ped faces; common, medium and fine, soft and hard, brownish and black concretions occur in pale brown silty clay loam pockets; very few roots; pH 7.0; gradual boundary.

B3 - 68 to 89 inches (173-226 cm), composed of colors, yellowish brown (10YR 5/4), gray (10YR 6/1) with very dark gray stains; silty clay loam; weak, medium blocky structure; very firm when moist; roots are rare; scattered brown and black concretions; pH 7.5; gradual boundary.

C - 89 inches + (226 cm+), gray (10YR 6/1) with coarse brown (10YR 5/4) mottles; silty clay loam and shale; massive; pH 8.0.

Pedon Description

<u>Site III - Intermound Soil Pedon No. 0</u>

(Colors are for moist soil unless otherwise stated).

A11 - 0 to 6 inches (0-15 cm), very dark grayish brown (10YR 3/2) fine sandy loam; grayish brown (10YR 5/2) when moist; weak medium granualr structure; very friable; very porous; common worm casts; many thin fragments of sandstone average thickness 1 to 5 cm in diameter and 2 to 5 mm in thickness; few platy sandstone fragments, 10 cm in diameter; (sandstone hardness of 2 on Mohes scale) surface of sandstone stained with soil color; interior sandstone colors dark yellowish brown, light olive brown; pH 5.5; gradual boundary.

A12 - 6 to 9 inches (15-23 cm) dark brown (10YR 3/3) fine sandy loam; dark brown (10YR 4/3) when dry; weak medium granualr sturcture; very friable; few worm casts; porous; common thin platy fragments of sandstone 1 to 5 cm in diameter and 2 to 5 mm in thickness; (sandstone hardness of 2 on Mohes scale) surface of sandstone stained with soil color; interior sandstone colors dark yellowish brown, light olive brown with streaks of very dark brown; pH 5.5; gradual boundary.

C1 - 9 to 15 inches (23-38 cm) strong brown (7.5YR 5/6) fine sandy loam; brownish yellow (10YR 6/6 when dry; weak fine granular structure; very friable; few worm casts; common thin fine fragments of sandstone and few fragments 5 cm in diameter; surface of sandstone stained with soil colors; sandstone interior colors dark yellowish brown, light olive brown with streaks of very dark brown; pH 5.5; gradual boundary.

C2 - 15 to 18 inches (38 to 46 cm) strong brown (7.5YR 5/8) fine sandy loam; brownish yellow (10YR 6/8) when dry; massive to weakly platy structure; friable; few fragments of sandstone and many thin lenses of siltstone; siltstone lenses have colors of yellowish red (5YR 5/6) and grayish brown (10YR 5/2) and range 1 to 3 cm in diameter and 1 and 2 cm in thickness; pH 5.0; abrupt boundary.

R - 18 inches (46 cm+); dark yellowish brown, light olive brown and very dark brown, sandstone, 3 hardness of Mohes scale.

Pedon Description

Site III - Intermound Soil Pedon No. 4

Profile No 4 was sampled in the mounded soil 55 feet from the intermound or 0 excavation. Five profiles of the mounded soils were described at intervals of 5 feet extending at 90 degrees through the mound. Profile 4 is considered representative of the mounded soils. (Colors are moist unless otherwise stated).

A11 - 0 to 10 inches (0-25 cm) very dark grayish brown (10YR 3/2) fine sandy loam; grayish brown (10YR 5/2) when dry; weak medium granular structure; very friable; many fine channels and worm casts; few crotovinas 5 cm in diameter; many fine platy fragments of sandstone 1 to 2 cm in diameter and 2 to 4 mm in thickness; few sandstone fragments 3 to 7 cm in diameter fragments have sharp to slightly weathered edges and corners; surface of fragments stained with soil colors; interior sandstone fragment colors range yellowish borwn, light olive brown and streaks of very dark brown; pH 6.0; gradual boundary.

A12 - 10 to 17 inches (25 to 43 cm), dark brown (7.5YR 3/2) fine sandy loam; grayish brown (10YR 5/2) when dry; weak medium granular structure; very friable; few crotovinas and holes 5 cm in diameter; many fine channels and worm casts; numerous earth worms; (1 to 3 earthworms in many spade excavations); many fine platy fragments of sandstone .5 cm to 1 cm size and 2 mm in thickness; few sandstone fragments 5 cm in diameter, sharp to slightly weathered corners, surfaces stained with soil colors, interior sandstone light olive brown; pH 6.0; gradual boundary.

B1 - 17 to 22 inches (43 to 56 cm), dark brown (7.5YR 4/2) fine sandy loam; brown (7.5YR 5/2) when dry; weak medium prismatic and fine granular structure; very friable; few crotovinas and open holes 5 cm in diameter; many fine channels and worm casts; few thin platy fragments of sandstone 2 to 4 cm in diameter; surface stained with soil color, interior light olive brown; surface of a few very fine, .5 cm in diameter; sandstone coated with yellowish red (10YR 4/6); pH 5.2; gradual boundary.

B2 - 22 to 26 inches (56-66 cm), dark brown (7.5YR 4/4) fine sandy loam; brown (7.5YR 5/4) when dry; weak medium prismatic and fine granular structure; very friable; many fine channels, and worm casts; few thin platy fragments of sandstone 1 to 5 cm in diameter; surface stained soil color; interior is light olive brown;

C - 26 to 28 inches (66 to 71 cm) strong brown (7.5YR 5/8) fine sandy loam; brownish yellow (10YR 6/8) when dry; massive; few fragments of sandstone; few yellowish red lenses of silt-stone; pH 5.0; abrupt boundary.

R - 28 inches (71 cm+) light olive brown sandstone; 3 hardness on Mohes scale.

CHAPTER V

RESULTS AND DISCUSSION

Location of Mounded Soils in Oklahoma

Figure 6 shows the general distribution of mounds in Oklahoma in comparison to climatography of the associated area. As indicated on the map, there is a close resemblance of the area to the 101.6cm plus rainfall belt. Mounds are less numerous toward the north and come to an abrupt ending near the west boundary of the area.

Topographic Measurements of Mounds in Site I

Forty-six mounds located in the 3.25ha meadow containing Site I have an average density of about 3.5 mounds to the acre (Figure 7). There is no definite pattern of arrangement except a relatively similar distance between each mound. Mound sizes and diameters were also similar.

Vegetation

The herbaceous forage comprising the vegetation of the 3.25ha meadow consisted mainly of tall and mid grasses, sedges and forbs. The meadow had been well managed and was considered to be in excellent vegetative condition. The meadow had been used for hay production with no record of commercial fertilizer applied during the past 25 year.

The average weight per hectare production of forage on the mound

AREA CONTAINING MOUNDED SOILS IN OKLAHOMA RELATIVE TO NORMAL ANNUAL TOTAL PRECIPITATION (1931-1960)

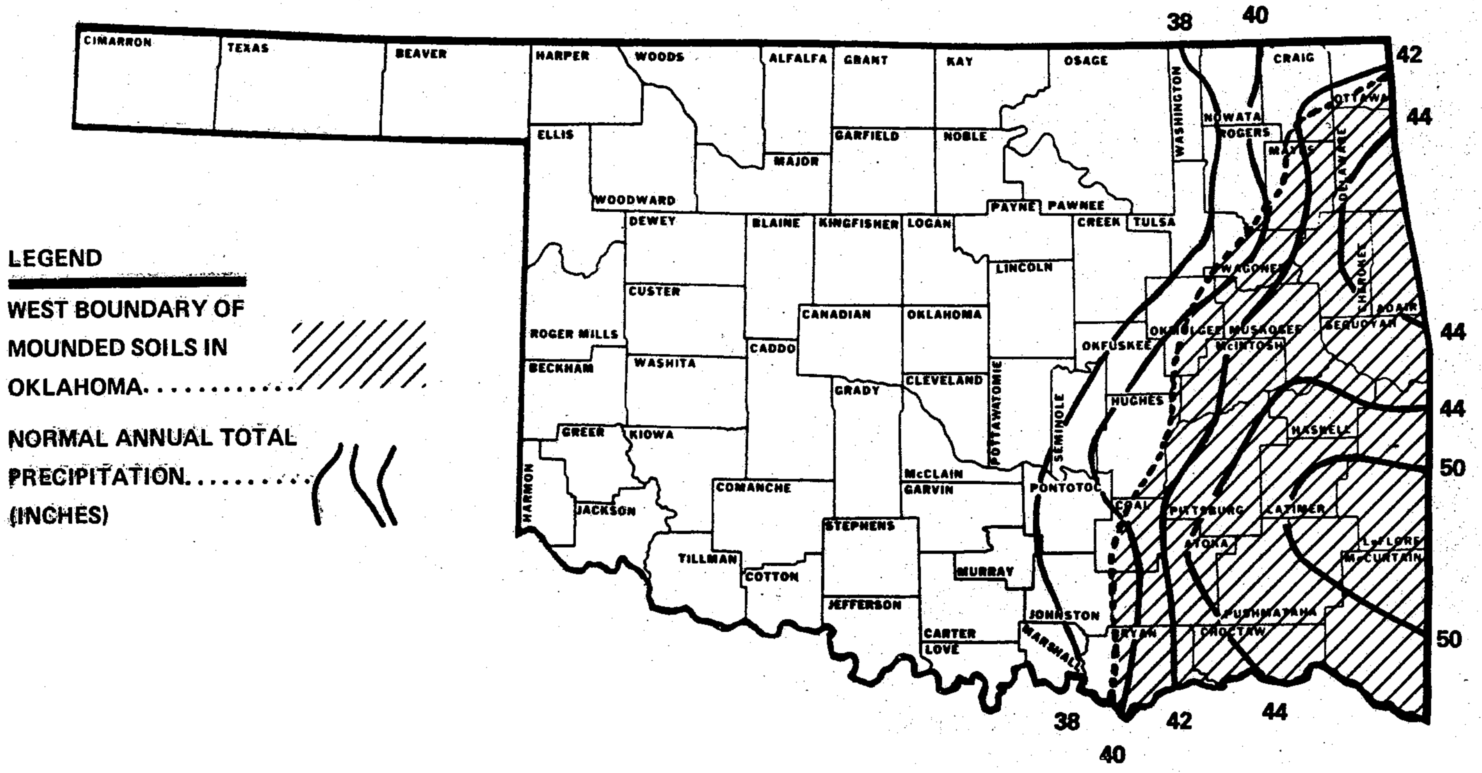


Figure 6. Distribution of Mounds in Oklahoma Compared to Climatography

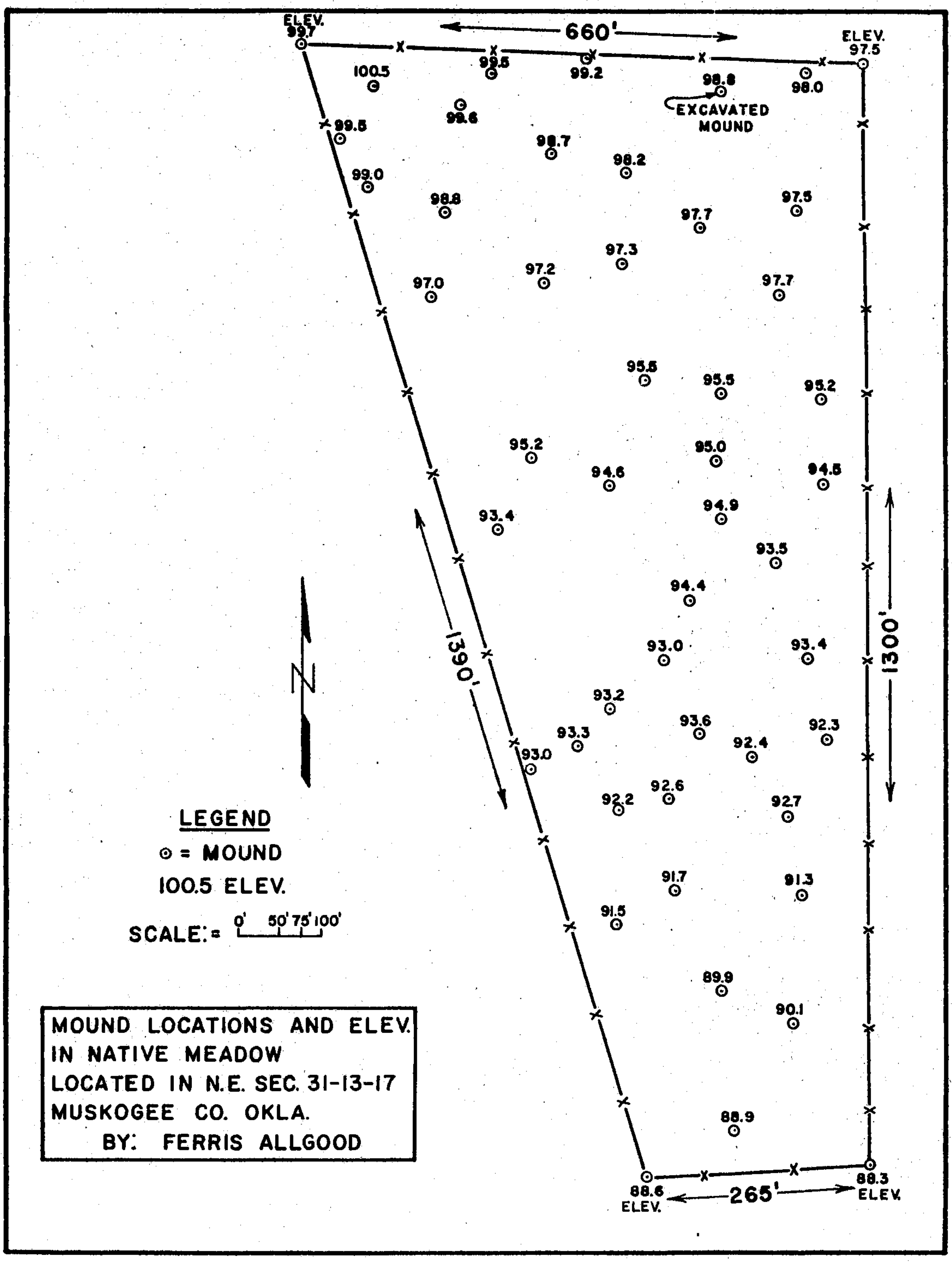


Figure 7. Topographic Measurements of Mounds in Site I.

was 4997 kg opposed to 3227 kg production from the mound interspace area. A part of the greater weight of forage on the mound was attributed to the more bulky gamagrass which comprosed 37 percent of the plant composition on the mound in contrast to 14 percent in the mound interspace area. In heavily grazed areas it has been observed to be the reverse of these measurements because the livestock tend to utilize the mound area more vigorously. Weights and compositions of the plant population were determined in late August, 1971. The percentage of plant composition on the mound and intermound of Site I is shown in Tables (II) and (III).

Evaluations of Soil Characteristics in Pedons of Site I.

A profile comparison of the elevations of soil horizons and special features in a 90 degree direction from true north in the mound and intermound are shown in Figure 8. Mounded soils have a 60% increase in thickness of the A1 and a 50% increase in the A2 horizons toward the interior of the mound as compared to the intermound area. Elevations of the upper and lower boundaries of the argillic horizon have similar positions in the mounded soils and intermound soils. Soil horizons of the intermound contained smooth boundaries and are relatively consistent in width in contrast to the more varied horizons of the mounded soils (Figures 9 and 10).

Soil development in Site I was indicated by the presence of a prominent argillic horizon in each pedon described. Nine soil pedons were described in the mounded space with the representative given in pedon 3. The representative soil of the intermound space is presented in pedon designated as O.

TABLE II

PERCENT VEGETATION COMPOSITION ON MOUNDS

Name	Percent
Little bluestem (Schizachyrium scoparius)	7
Eastern gamagrass (Tripsacum dactyloides)	39
Big bluestem (Andropogon gerardii)	14
Spike sedge (Eleocharis sp.)	7
Yellow bristlegrass (Setaria lutescens)	4
Purpletop (Tridens flavus)	4
Fall witchgrass (Leptoloma cognatum)	4
Field Paspalum (Paspalum laeve)	4
Globe flat sedge (Cyperus ovularis)	4
Bushy bluestem (Andropogon glomeratus)	4
Slender fleabane (Erigeron tenuis)	4
Switchgrass (Panicum virgatum)	4
Indiangrass (Sorgastrum nutans)	4

TABLE III

PERCENT VEGETATION COMPOSITION ON INTERMOUND

Name	Percent
Rattlesnake master	3
Common milkweed (*Asclepias syriaca*)	3
Eastern gamagrass (*Tripsacum dactyloides*)	18
Bushy bluestem (*Andropogon glomeratus*)	9
Meadow dropseed (*Sporobolus asper* (var. *hookeri*)	6
Field Paspalum (*Paspalum laeve*)	3
Spike sedge (*Eleocharis* sp.)	6
Big bluestem (*Andropogon gerardii*)	9
Switchgrass (*Panicum virgatum*)	6
Indiangrass (*Sorghastrum nutans*)	12
Winter rosett (*Panicum* sp.)	3
Splitbeard bluestem (*Andropogon ternarius*)	3
Compassplant (*Silphium laciniatum*)	3
Leadplant (*Amorpha canescens*)	3
Catclaw (*Schrankia uncinata*)	3
Scaleseed (*Spermolepis divaricatus*)	3
Scaly gayfeather (*Liatris squarrosa*)	3
Kansas gayfeather (*Liatris pycnostachya*)	3

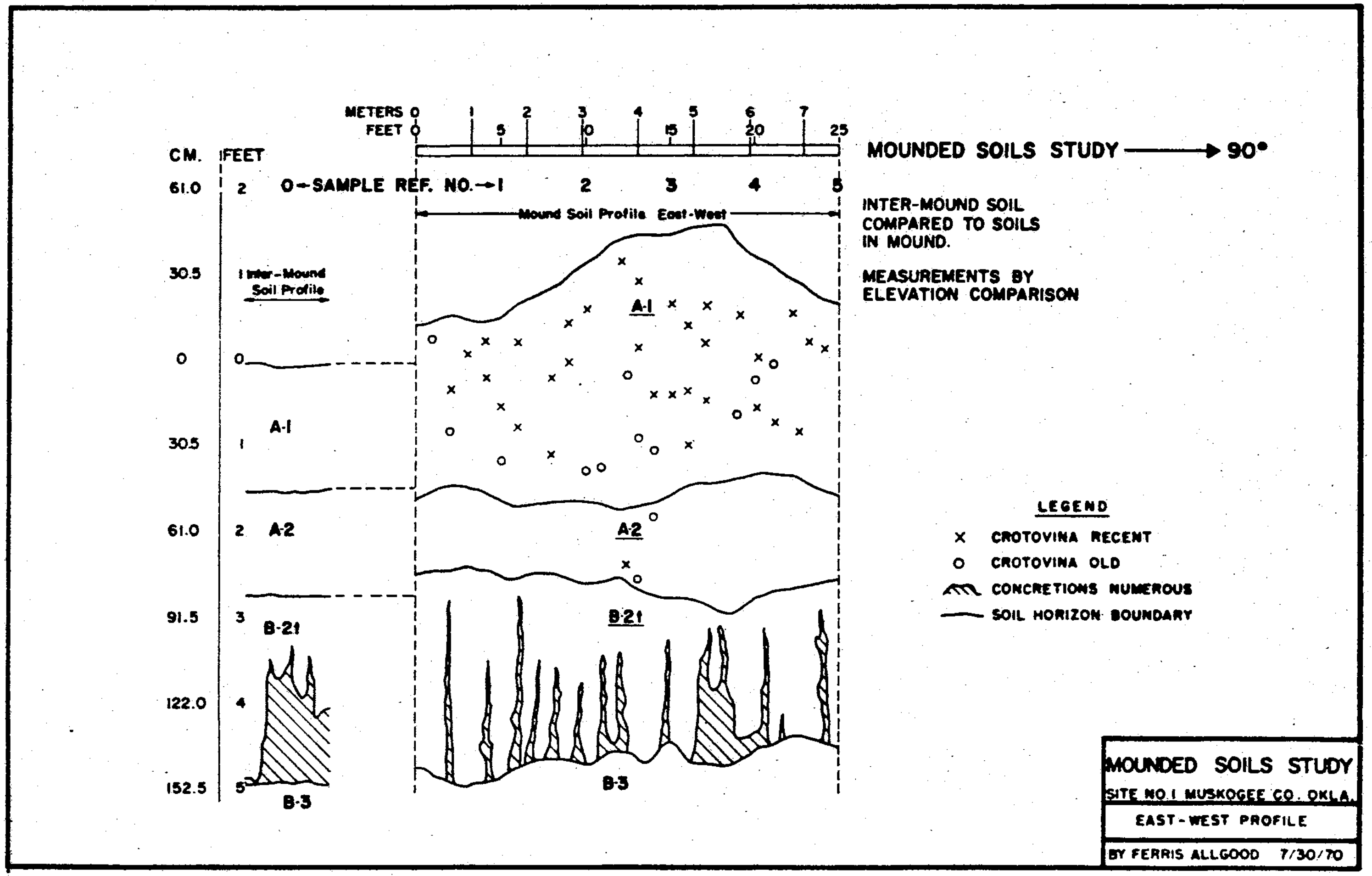


Figure 8. A Profile Comparison of Elevations of Soil Horizons and Special Features in a 90 Degree Direction in the Mound and Intermound - Site I.

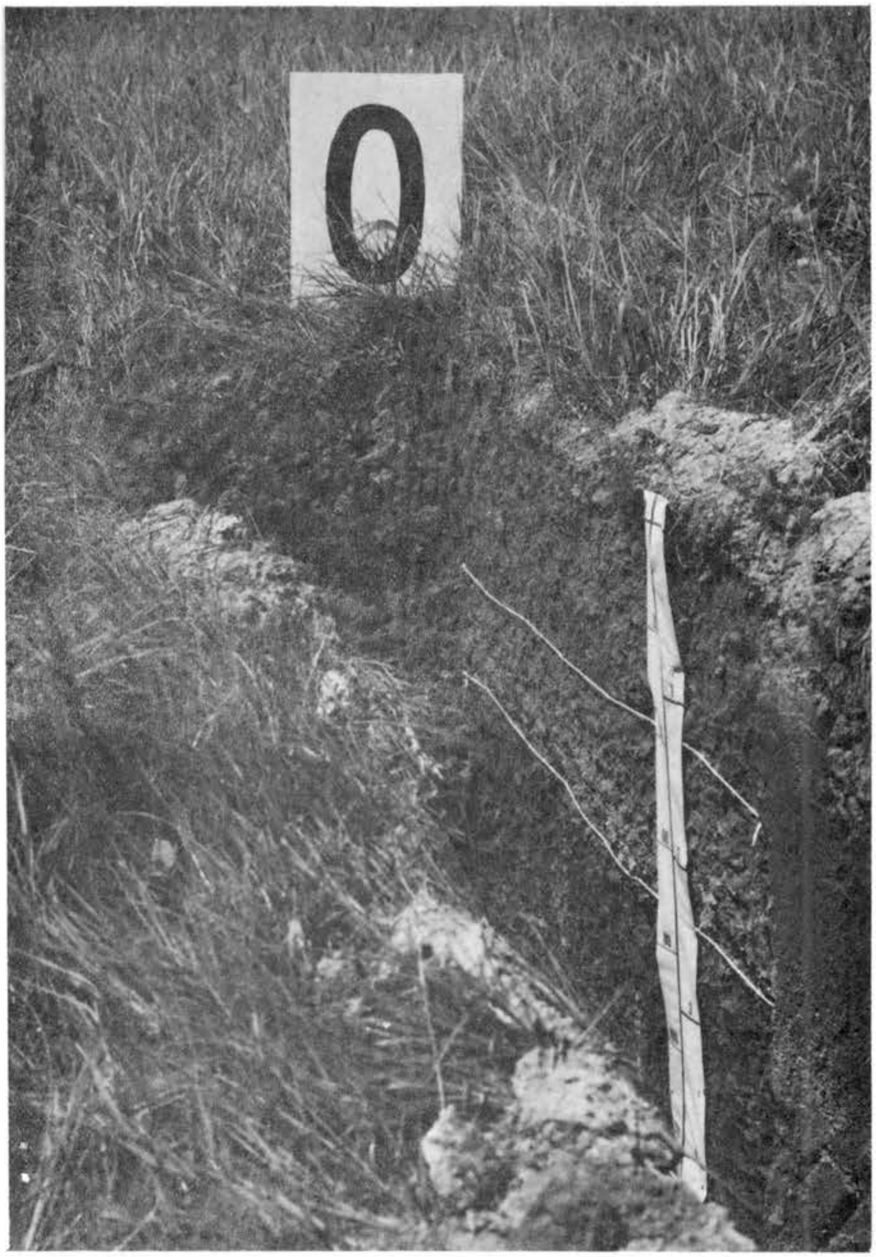


Figure 9. 0 represents the intermound soils of the site. The smooth horizon boundaries marked by white rug yarn are characteristic of the intermound soil pedons.

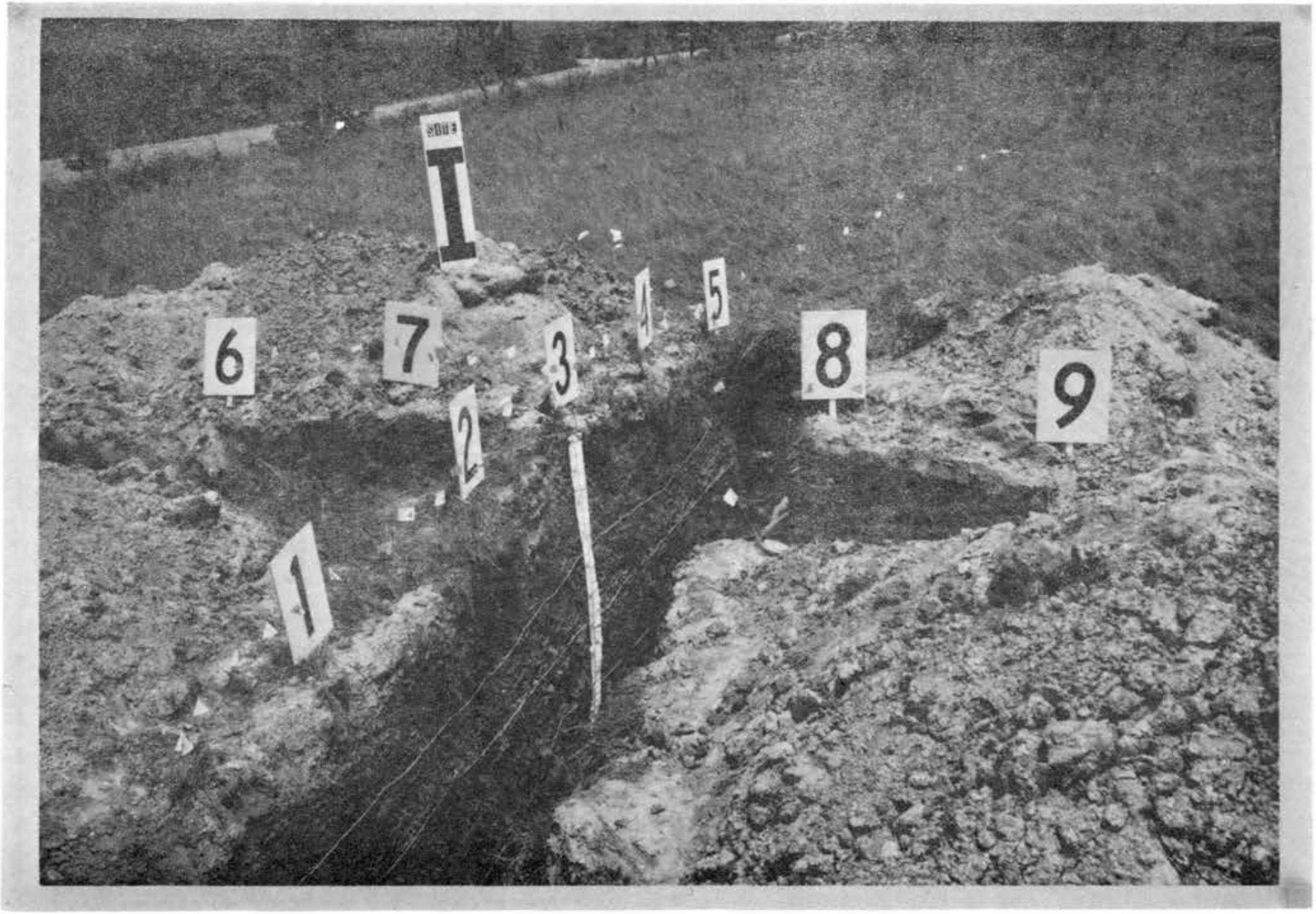


Figure 10. Soil horizons, marked by white rug yarn, show their variations through the mound in a 90 degree direction. Numbers mark pedons described in the site.

A significant contrast between pedons of the mound and intermound was the percentage of clay present in the upper boundaries of the illuviated layers. Clay translocation in the intermound pedon number 0 is marked with an abrupt textural change between the eluviated and illuviated layers, while in the mounded soil pedon a more gradual clay increase formed the upper boundary of the argillic horizons.

Uniformity in the arrangement of the A1 horizon and the increase in thickness of the A2 horizon toward the interior of the mound is evidence the mound has been in place for an extended time. This is further indicated by the gradual textural change in the argilleous horizon of the mounded soils. Nikiforoff (57) reported similar conditions while studying mounds on hardpan soils in California. He referred to these conditions as "windows" in the hardpan. Ross et. al. (74) reported a difference in clay distribution in the mound compared to the intermound area. Similarities of elevations of the upper and lower boundaries of the argillic horizon in the mound and intermound of this study indicate the boundaries were established before the inception of the mound.

Biological Evidences

A close correlation existed between the degree of mottling and evidences of biological activity. Where mottling due to extended wetness decreased, evidence of biological activity increased. The argillic horizons were void of worm casts and crotovinas. Crotovinas in the A horizons were numerous and were classed as new and old. Those classed as old contained similar soil structure to the surrounding horizon. Those classed as new contained structure in the interior contrasting the surrounding soil. Locations of the older crotovinas were consistently in the lower depths (Figure 8). Measurements of crotovinas exposed ranged mostly between 4 to 12 cm. in diameters. Four exceptions measured ranged between 18 and 34 cm. in diameter. Two contained evidences of litter in the soil mass. Several crotovinas were observed to contain a platy "onion skin" structure around the outer wall. Crotovinas in two exposures contained lighter colored soil than that of the surrounding matrix.

One small crotovina was found to extend downward to terminate at the upper surface of the argillic horizon. Downshafts have been puzzling for sometime in mole fortresses in England and the Neurotrichus in Oregon (Dalquest et. al. (19)). Some observers have speculated that these structures are wells to supply water for the mole.

Crotovinas were relatively easy to locate in the soil pedons (Figures 11 and 12).

Large volumes of organic matter are added to mounds in the form of rodent nests. New and old nests were often encountered in mound sites investigated. These nests were primarily constructed by the pocket gopher Geomys bursarius dutcheri (Glass (30)). The pocket gopher is very particular and requires luxurious beds. When one becomes soiled and old a new one is constructed (Criddle (18)). The pocket gopher Geomys bursarius dutcheri increases in number about the mounds in the fall and remains until late spring. Mounds are favorite places to deliver their young, probably in an attempt to escape wet conditions. The gestation period is during late winter and early spring which coincides with the wettest seasons of the region (Figure 13).

Average size of the earth casts surfaced by pocket gophers are 20

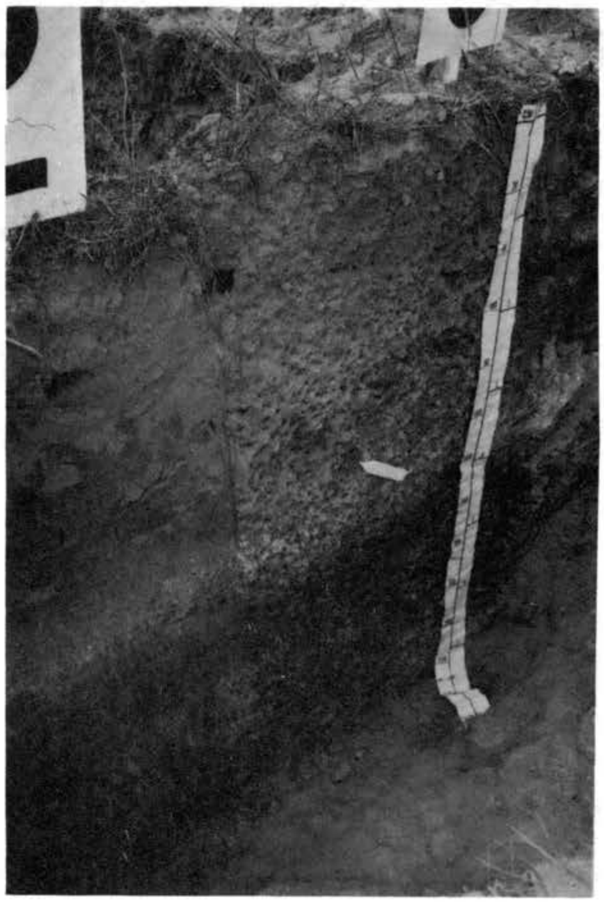


Figure 11. Crotovina location as shown in Pedon 3.

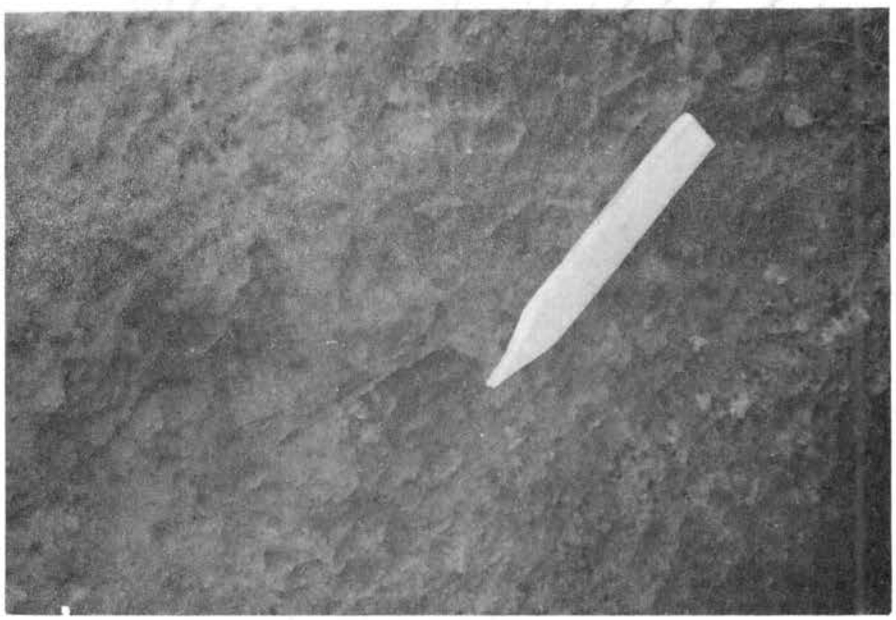


Figure 12. A close up of the crotovinas shown in pedon 3.

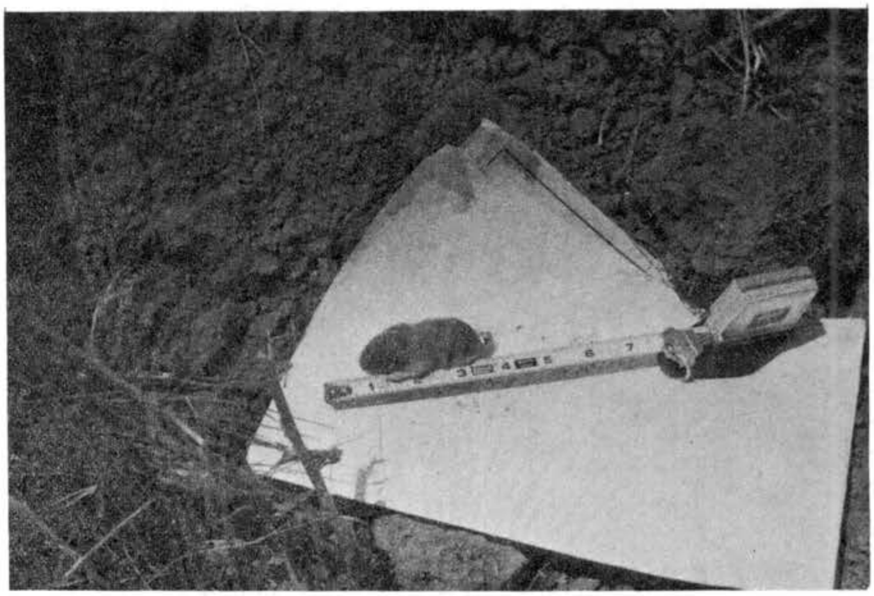


Figure 13. Young pocket gopher *Geomys bursarius dutcheri* in early March.

to 38 cm in diameter and less than 12 cm in height. In the many sites visited during this study only three larger excavations were observed. A large earth cast constructed by a pocket gopher measured 104 cm in diameter and 38 cm in height. Its interior contained a finely shredded ball of grass litter surrounding a cache of Bermuda grass (Cynodern dactylon) stolons. English (23) reported similar excavations by pocket gophers on wet land in Brazos County, Texas. A similar large excavation made by a pocket gopher in the interspace associated with large mounds was observed for two years following its construction with no indication of rodent use (Figure 14). Activity of pocket gophers was intense in the site during the particular season of construction, which may have been traceable to the heavy grazing of the vegetation. Buechner (15) reported heavy use of surface vegetation by livestock caused an increase in pocket gopher activity. Other reasons for an increase in soil excavating by the pocket gopher were associated with the gestation period and to close out light (Miller (51) and Miller and Bond (60)).

In this study a washtub was found completely filled with soil which may have been associated with a hole in the bottom of the tub (Figure 15).

The Pocket gopher Geomys bursarius dutcheri occurs in a territory that extends to the central part of Oklahoma (Glass (30)). This extends well over a hundred miles west of the area occupied by the mounds.

The Eastern or Common Mole Scalopus aquaticus also delivers its young in the higher elevations of wet landscapes. They also visit the mounds in search of food which is the earthworm Lumbricus terrestris

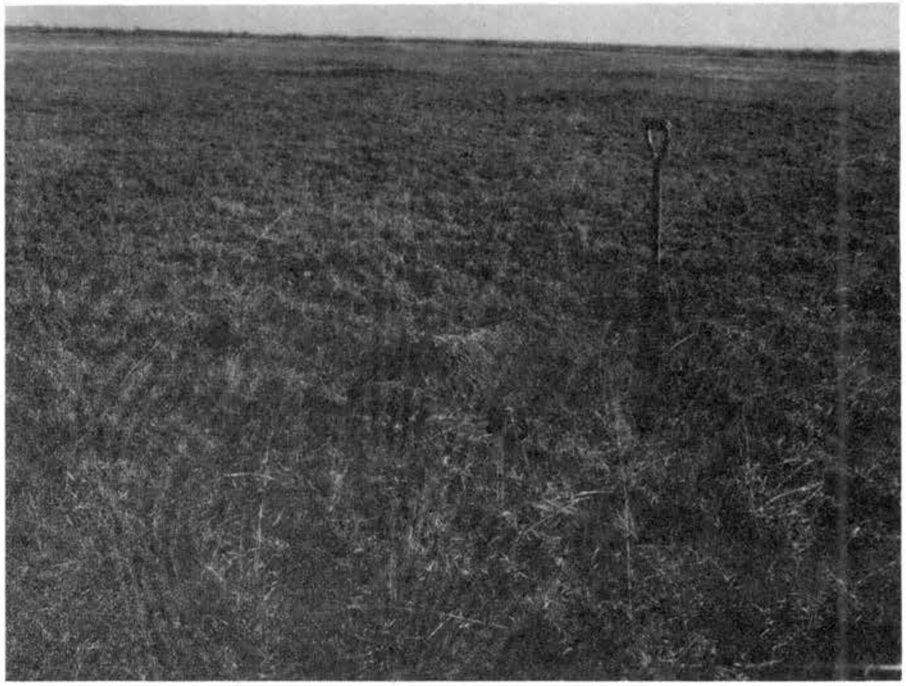


Figure 14. Excavated soil observed in association with large mounds. The excavation was the work of a pocket gopher.

Figure 15. A washtub was completely filled with soil by a pocket gopher. Note the hole in the tub which may have prompted an effort to close out light.

and the white grub Lachnosterna fusca (Arlton (3)). The concentration of mole activity varied in locations observed in the study. Some highly populated areas of moles and earthworms occurred in locations west of Rile in the west edge of McIntosh County. Soils having dense claypan characteristics were commonplace in the intermound polypedons. The active territory of the Eastern or Common Mole Scalopus aquaticus extends across Oklahoma excluding the Panhandle (Palmer (59)).

In landscapes containing mounds water accumulation on a sublayer was a characteristic during the wet seasons. In Site I water accumulates on the surface of the argillic horizon for several days following periods of precipitation. The condition may persist throughout the winter and spring months. Migration of rodents to the mounds is easily associated with the arrival of cool or wet weather. It is also evident that the mound is a choice habitat for other organisms. The hydrologic condition of the micro landscape apparently also determines the earthworms' choice of soil.

Parker and Parskley (60), gave accounts of the migration of earthworms according to moisture. Nakamura (53) gave accounts of earthworm migration according to temperature. Earthworms survive extreme conditions but will move from wet, cold or heated soil to more agreeable conditions. It has also been demonstrated that earthworms move into soil materials high in organic matter (Prosser (66), Reynierse (70)). The decayed material of the many nests abandoned by the pocket gopher Geomys bursarius dutcheri and the mole Scalopus aquaticus in the mounded soils of Eastern Oklahoma probably accounts for the considerable concentration of the Lumbricus terrestris. Worm channels were also very numerous in the dark colored crotovinas. The earthworms may have a role in the formation of the gradual textural change between the eluviated and illuviated horizons of the mounded soil pedons. Their presence may also contribute to the greater forage yields on the mounds of the meadow containing Site I. Puh (67) showed that soil which had passed through the earthworm alimentary tract had a change in pH from a 6.2 to 6.8. Where the parent soil was calcareous, the pH was reduced from 7.8 to 7.5. In the same study it was shown that soluble or available phosphorus, potassium, nitrogen, calcium, and humus were also higher in worm casts. Lunt and Jacobson (43) found greatest increases in worm cast in available phosphorus, exchangeable potassium and magnesium. The increases were threefold to elevenfold greater than the surrounding soil. Campbell, cited by Prosser (66), concluded from his study that Lumbricus terrestris possesses an urea cycle. This may be a nitrogen source. Robertson (72) showed that earthworms may decompose calcium carbonate concretions in their calciferous glands and the secretions containing calcium are mixed with the food source. Secretion can take place under acid, neutral, or alkaline conditions, provided the worm has access to material containing calcium carbonate.

Calcium in worm casts would be mobile. With this consideration the analyses may be interpreted to further substantiate the concentration of earthworms in the mound (Tables IV, V). Percentages of calcium are less in the A horizons of the mounded soils than the intermound but increase to a higher percentage with depth. In comparison, phosphorus is not so easily translocated. Phosphorus averages much higher in the mounded soil than in the intermound. Magnesium may be less mobile than calcium. Magnesium averaged much higher in the

TABLE IV

CHEMICAL AND PHYSICAL ANALYSES OF INTERMOUND SOIL PEDON NO. 0

PROFILE DESCRIPTION:

SAMPLE NUMBER	HORIZON	DEPTH	THICKNESS	COLOR (M)	TEXTURE	STRUCTURE	CONSISTENCE
70-OK-51- 0- 1	A11	0- 9"	9	10.0YR 3/2	SIL	1FGR	MFR
70-OK-51- 0- 2	A12	9- 18"	9	10.0YR 4/2	SIL	1FGR	MFR
70-OK-51- 0- 3	A21	18- 26"	8	10.0YR 5/3	SIL	1MGR	MFR
70-OK-51- 0- 4	A22	26- 31"	5	10.0YR 6/2	SIL	2MGR	MFR
70-OK-51- 0- 5	B21T	31- 43"	12	10.0YR 5/2	C	2MBK	MVFI
70-OK-51- 0- 6	B22T	43- 55"	12	10.0YR 5/2	C	2MBK	MVFI
70-OK-51- 0- 7	B3CN	55- 71"	16	10.0YR 5/3	C	1VFBK	MVFI
70-OK-51- 0- 8	C	71- 86"	15	10.0YR 5/3	SIC		

CHEMICAL DATA: ANALYST: D. BAKHTAR

SAMPLE NUMBER	PH1:1		CEC	EXTRACTABLE CATIONS,MEQ/100 GMS						%BASE SATURATION		%	P.P.M.
	H2O	KCL		H	CA	MG	K	NA	AL	NAAC	SUM OF CAT.	OM	TOTAL P
70-OK-51- 0- 1	5.9	4.9	9.4	3.18	2.26	2.80	0.12	0.15	0.14	57.1	62.7	2.26	214.8
70-OK-51- 0- 2	6.2	4.8	8.2	1.52	2.38	1.81	0.09	0.24	0.11	55.2	74.8	1.61	193.7
70-OK-51- 0- 3	6.1	4.5	6.7	1.26	1.58	1.36	0.07	0.30	0.53	49.2	72.5	1.10	161.8
70-OK-51- 0- 4	6.0	4.5	7.3	0.73	1.24	1.84	0.07	0.57	0.47	51.0	83.7	0.57	152.3
70-OK-51- 0- 5	6.1	5.1	25.2	4.23	8.45	8.31	0.38	2.83	0.00	79.3	82.6	0.74	145.0
70-OK-51- 0- 6	6.8	5.6	22.3	1.91	7.36	9.03	0.31	3.00	0.00	88.6	91.2	0.96	183.2
70-OK-51- 0- 7	7.0	6.0	27.5	1.55	9.95	11.13	0.46	4.15	0.00	93.5	94.4	0.51	184.6
70-OK-51- 0- 8	7.1	6.1	22.9	0.99	10.79	9.57	0.39	3.80	0.00	107.2	96.2	0.39	201.4

PHYSICAL DATA: ANALYST: D. BAKHTAR

SAMPLE NUMBER	%SAND	%SILT	%CLAY	TEXTURE	%>2MM	% SAND SUBFRACTIONS				
						%VCS	%CS	%MS	%FS	%VFS
70-OK-51- 0- 1	15.6	76.8	7.6	SIL	0.5	0.5	1.0	0.6	2.2	11.4
70-OK-51- 0- 2	15.0	79.2	5.7	SIL	1.3	0.8	1.2	0.6	2.2	10.4
70-OK-51- 0- 3	43.2	48.8	8.0	L	5.6	1.5	1.1	0.5	2.3	38.0
70-OK-51- 0- 4	11.4	78.9	9.7	SIL	16.2	2.2	1.1	0.5	2.0	5.7
70-OK-51- 0- 5	9.6	53.9	36.5	SICL	3.3	0.7	0.7	0.5	1.6	6.4
70-OK-51- 0- 6	8.6	55.1	36.2	SICL	6.0	0.3	0.5	0.4	1.6	6.0
70-OK-51- 0- 7	9.6	49.0	41.4	SIC	2.3	0.6	0.6	0.7	1.8	6.2
70-OK-51- 0- 8	8.6	52.7	38.7	SICL	2.7	0.5	0.4	0.4	1.5	6.0

INTERPRETIVE CALCULATIONS:

SAMPLE NUMBER:	CA/MG	CEC/CLAY	CLAY FREE PARTICLE SIZE DISTRIBUTION					
			% SILT	% VCS	% CS	% MS	% FS	% VFS
70-OK-51- 0- 1	0.81	123.68	83.12	0.54	1.08	0.65	2.38	12.34
70-OK-51- 0- 2	1.31	143.86	83.99	0.85	1.27	0.64	2.33	11.03
70-OK-51- 0- 3	1.16	83.75	53.04	1.63	1.20	0.54	2.50	41.30
70-OK-51- 0- 4	0.67	75.26	87.38	2.44	1.22	0.55	2.21	6.31
70-OK-51- 0- 5	1.02	69.04	84.88	1.10	1.10	0.79	2.52	10.08
70-OK-51- 0- 6	0.82	61.60	86.36	0.47	0.78	0.63	2.51	9.40
70-OK-51- 0- 7	0.89	66.43	83.62	1.02	1.02	1.19	3.07	10.58
70-OK-51- 0- 8	1.13	59.17	85.97	0.82	0.65	0.65	2.45	9.79

TABLE V

CHEMICAL AND PHYSICAL ANALYSES OF MOUNDED SOIL PEDON NO. 3

PROFILE DESCRIPTION:

SAMPLE NUMBER	HORIZON	DEPTH	THICKNESS	COLOR (M)	TEXTURE	STRUCTURE	CONSISTENCE
70-OK-51- 3- 1	A11	0- 19"	19	10.0YR 3/2	SIL	1FGR	MFR
70-OK-51- 3- 2	A12	19- 29"	10	10.0YR [illegible]/2	SIL	2FGR	MFR
70-OK-51- 3- 3	A21	29- 36"	7	10.0YR 5/3	SIL	2FGR	MFR
70-OK-51- 3- 4	A22	36- 40"	4	10.0YR 4/3	SIL	1FGR	MFR
70-OK-51- 3- 5	A23	40- 47"	7	10.0YR 5/4	SIL	1FGR	MFR
70-OK-51- 3- 6	B21T	47- 54"	7	10.0YR 5/4	CL	2FBK	MVFI
70-OK-51- 3- 7	B22T	54- 68"	14	10.0YR 5/4	C	1MSBK	MVFI
70-OK-51- 3- 8	B3	68- 89"	21	10.0YR 5/4	C	1MBK	MVFI
70-OK-51- 3- 9	C	89-100"	11	10.0YR 6/1	C	M	

CHEMICAL DATA: ANALYST: D. BAKHTAR

SAMPLE NUMBER	PH1:1 H2O	PH1:1 KCL	CEC	EXTRACTABLE CATIONS,MEQ/100 GMS H	CA	MG	K	NA	AL	%BASE SATURATION NAAC	SUM OF CAT.	% OM	P.P.M. TOTAL P
70-OK-51- 3- 1	5.1	4.3	8.2	4.75	1.39	2.57	0.09	0.10	0.44	50.8	46.7	1.86	291.1
70-OK-51- 3- 2	5.8	4.7	7.6	2.93	1.35	2.72	0.08	0.12	0.05	56.1	59.4	1.45	257.3
70-OK-51- 3- 3	6.0	4.8	6.2	1.88	1.35	2.56	0.09	0.22	0.00	68.6	69.3	0.55	179.2
70-OK-51- 3- 4	6.5	5.1	4.6	0.87	1.02	2.22	0.07	0.20	0.00	76.9	80.1	0.47	213.7
70-OK-51- 3- 5	6.6	5.3	9.2	2.14	0.93	5.23	0.14	0.54	0.00	74.5	76.2	0.46	206.1
70-OK-51- 3- 6	6.7	5.5	17.6	3.53	6.12	5.70	0.20	1.04	0.00	74.2	78.8	0.58	205.4
70-OK-51- 3- 7	7.2	6.0	20.9	3.13	8.15	6.88	0.23	1.41	0.00	79.8	84.2	0.54	280.2
70-OK-51- 3- 8	7.4	6.3	31.6	3.29	11.94	12.34	0.37	2.41	0.00	85.6	89.2	0.50	338.0
70-OK-51- 3- 9	7.6	6.2	31.6	3.02	13.77	10.00	0.35	2.46	0.00	84.1	89.8	0.47	316.2

PHYSICAL DATA: ANALYST: D. BAKHTAR

SAMPLE NUMBER	%SAND	%SILT	%CLAY	TEXTURE	%>2MM	% SAND SUBFRACTIONS %VCS	%CS	%MS	%FS	%VFS
70-OK-51- 3- 1	16.1	74.1	9.8	SIL	4.3	2.1	1.6	0.6	2.6	9.4
70-OK-51- 3- 2	16.7	76.7	6.6	SIL	5.1	1.1	1.3	0.6	2.8	11.0
70-OK-51- 3- 3	15.7	74.9	9.4	SIL	6.0	1.7	1.4	0.7	2.3	9.9
70-OK-51- 3- 4	19.3	74.7	6.0	SIL	5.6	1.4	1.3	0.6	2.7	13.6
70-OK-51- 3- 5	8.8	82.2	9.0	SI	15.9	1.4	1.0	0.5	2.4	3.7
70-OK-51- 3- 6	13.2	67.4	19.4	SIL	19.3	1.8	1.1	0.5	1.9	8.1
70-OK-51- 3- 7	9.7	52.4	37.8	SICL	7.3	1.1	0.7	0.4	1.4	6.4
70-OK-51- 3- 8	11.2	51.9	36.9	SICL	6.7	0.9	0.7	0.6	1.9	7.3
70-OK-51- 3- 9	14.4	48.7	36.9	SICL	11.8	0.6	0.5	0.5	1.8	11.0

INTERPRETIVE CALCULATIONS:

SAMPLE NUMBER:	CA/MG	CEC/CLAY	CLAY FREE PARTICLE SIZE DISTRIBUTION % SILT	% VCS	% CS	% MS	% FS	% VFS
70-OK-51- 3- 1	0.54	83.67	82.15	2.33	1.77	0.67	2.88	10.42
70-OK-51- 3- 2	0.50	115.15	82.12	1.18	1.39	0.64	3.00	11.78
70-OK-51- 3- 3	0.53	65.96	82.67	1.88	1.55	0.77	2.54	10.93
70-OK-51- 3- 4	0.46	76.67	79.47	1.49	1.38	0.64	2.87	14.47
70-OK-51- 3- 5	0.18	102.22	90.33	1.54	1.10	0.55	2.64	4.07
70-OK-51- 3- 6	1.07	90.72	83.62	2.23	1.36	0.62	2.36	10.05
70-OK-51- 3- 7	1.18	55.29	84.24	1.77	1.13	0.64	2.25	10.29
70-OK-51- 3- 8	0.97	85.64	82.25	1.43	1.11	0.95	3.01	11.57
70-OK-51- 3- 9	1.38	85.64	77.18	0.95	0.79	0.79	2.85	17.43

mounded soil pedon than in the intermound pedon.

Some of the physical effects of earthworms on the soil pedons were observable and may be interpreted with some certainty when comparing the mound and intermound pedons. The transfer of soil material from one horizon to the other by earthworms is indicated in the color of the casts. This was shown in pedon 3. In the mounded soil the transfer of soil between the A2 and A1 horizon was substantially more than in the intermound pedon and presents some obvious effect on the pedon. By receiving fresh organic material from the A1 horizon it prevents the A2 horizon from becoming a "dead horizon" where only mineral reaction takes place. This factor, plus the earthworms' return of illuviated soil upward, would assist in maintaining the higher base saturation of the epipedon of the mounded soil than that of the intermound soil and would also affect the gradual clay distribution at the surface of the argillic horizon. Base saturation maintained above 50 percent in the A2 horizon or the upward movement of the illuviated soil plasma are credible in the formation of the gradual textural change in the upper part of the argillic horizon of the mounded soil. Joffe (36) reports that high base saturation restricts clay mobility.

The earthworm may be justifiably credited with restricting degradation of the mounded soil pedon when compared to the intermound pedon. Pedon 0 of the intermound contains fewer worm casts, especially in the A2 horizon which also shows a lower base saturation. Further emphasizing the difference in soil development is an abrupt textural change between the A and B horizons of the intermound soil pedon 0.

Higher concentrations of earthworms about the mound undoubtedly contributes to the friable condition of the epipedon. Darwin (21) cited populations of 25 to 53 thousand worms per acre could pass ten to eighteen tons of soil annually through their alimentary tracts. The significance of earthworm contributions to the more porous epipedon of mounded soils may be the causal factor of lower soil density in the mounded soil when compared to the associated intermound (Figure 16).

Comparison of Pedons of Site III

Earthworms were found to be conspicuously more concentrated about mounds occurring in landscapes having shallow soils over sandstone. Soil pedon descriptions in 0 and 4 of Site III represent this type of condition. Mounds occurring on shallow soils over sandstone rock have been reported in other localities but are not common in this region (Malde (45)). Soil horizon thickness between the mounded soils and intermound soils are compared in Figure 17. Excessive ground water or internal drainage water travels in the underlying sandstone interstratified with shale and fissures as seeps or springs on the foot slopes of the site during the wetter seasons. Excavations of the site were made in mid summer while the soil was moderately dry. Greater soil depth in the mound contained a cooler, more moist soil than the intermound which probably accounted for the presence of one to three earthworms on numerous spade loads in the mounded soil compared to none occurring in the excavation of the associated intermound.

The dark colors of the epipedon extended to a greater depth in the mounded soil pedon than the intermound. Only one crotovina and one freshly constructed tunnel were located in the mounded soils with one tunnel in the intermound.

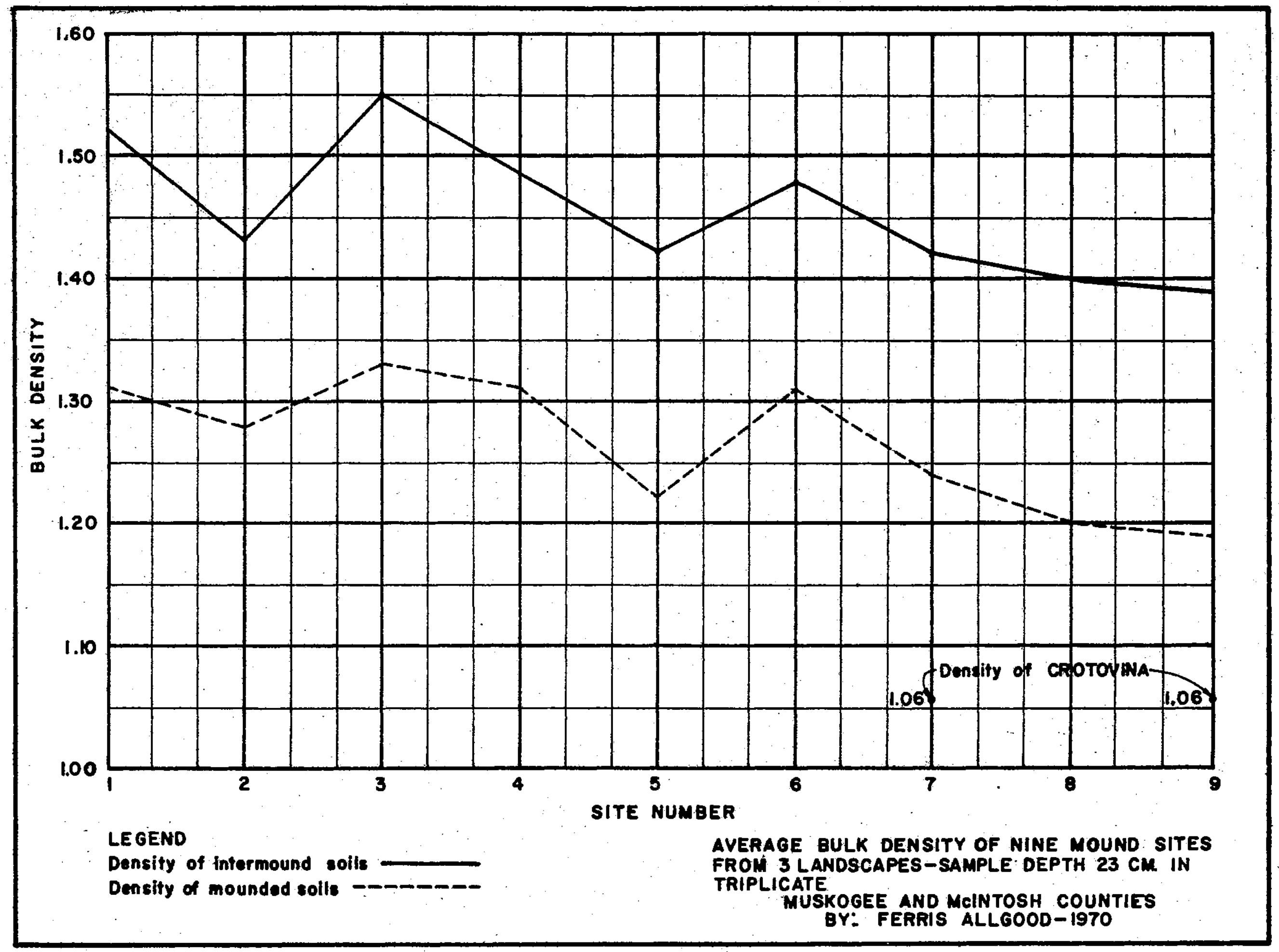


Figure 16. Bulk Densities of Mounded Soils and Associated Intermound Soils.

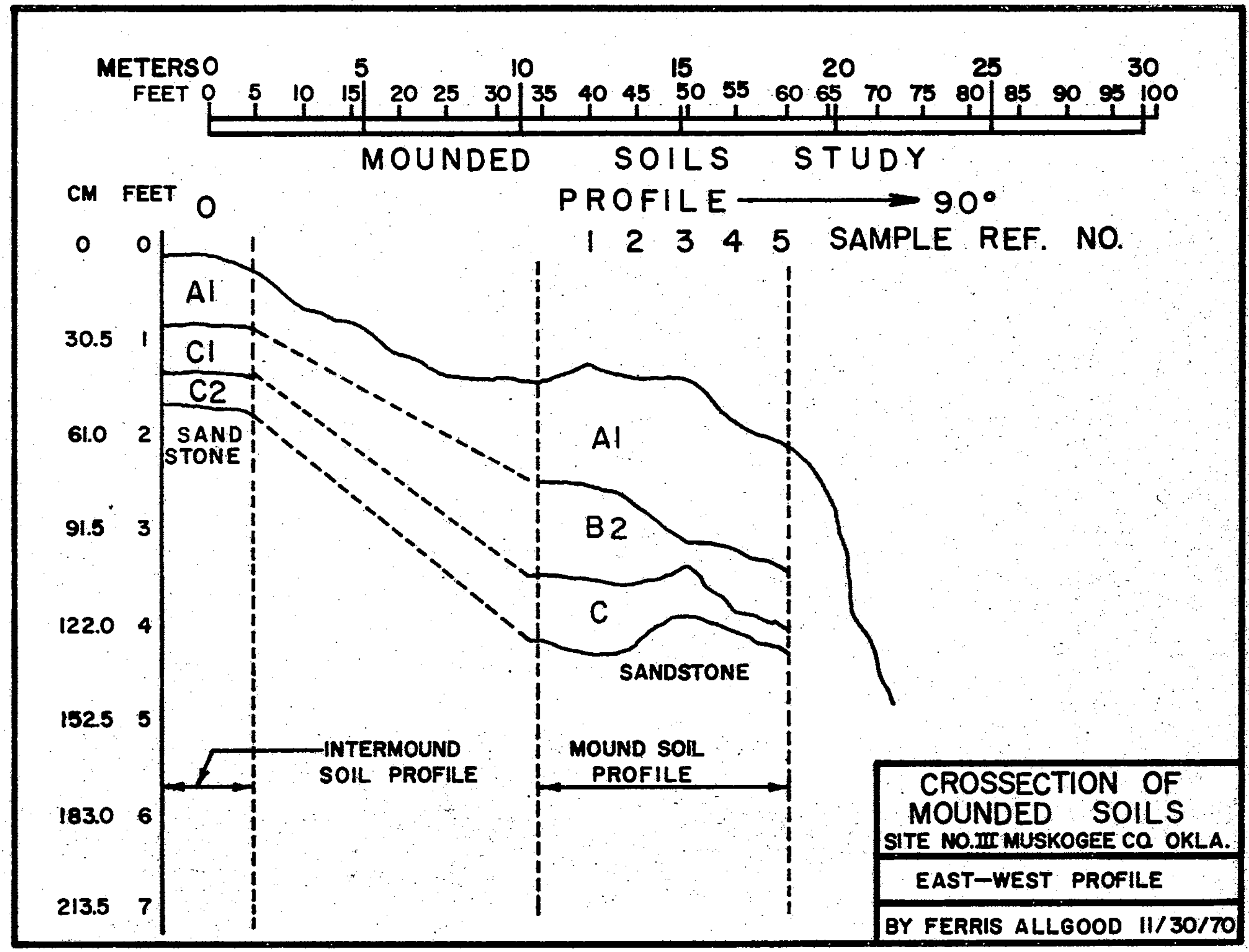


Figure 17. Profile View of Soil Horizons and Topography in Site III.

Bulk Density

Bulk density of the A1 horizon was less in the mounded soil epipedon than in the associated intermound soils in all sites sampled. Bulk density samples of mounded soils varied considerably from that of the intermound soil. The crotovinas were lower in density of the intermound soils than in the surrounding soil of the soil horizon. This consistent observation suggests that the formal epipedon of the mounded soil is more evenly worked by organisms. Spacing of the crotovinas indicates rodent activity alone is insufficient to sustain this consistent variation. Evidence obtained in this study indicates that the contribution of all organisms that thrive in or migrate to the higher elevation of the mound plays a part in sustaining the mounds. Mounds probably begin with some small rodent excavation. This is indicated by the deeper locations of the older crotovinas. All animal activity is more concentrated in soils having less mottling which indicates a tendency for these animals to concentrate in the drier soil which is in the elevated areas during that part of the year when excess water is present. This concentration of animals would account for the loose soil condition of the mound. The report that mounded soils are more friable than the intermound soils is commonly reported in literature regarding the mounds. Ross et. al. (74) found similar soil density comparisons as were obtained in this study. Density comparisons of mounds and intermounds of Eastern Oklahoma are shown in Figure 16.

Volume is increased by expanding a known density of the intermound soil. The significance of this increase is demonstrated by expanding the 1.48 density to a 1.22 density which are the data for mound number 6 (Figure 16). This expanded calculation presents a volume increase of about 21 percent. When using the same intermound data of 1.48 density and expanding it to the 1.06 density of the crotovina there is about a 40 percent increase in volume. The relationship of sizes of mounds in a particular landscape are therefore in part related to soil density. Rodent tunnels and other voids would also contribute to the size of the mound.

Erosion Effects on mound Sizes

Sheet erosion between the mounds acting over a long period of time is also considered significant in contributing to the height of the mounds. Supporting this conclusion is the greater variation of the heights of mounds in areas of concentrated surface drainage (Figures 18, 19, 20).

The resistance to erosion is a part of an equilibrium imposed by natural inhabitants of the mound. As inhabitants of the mound function to sustain their own preservation they contribute to the existence of the mound. The erosional slope containing the mound in Site III, unquestionably, indicates the mound sustains resistance to erosion. Ruhe (75) discusses the multidirectional erosional attack on the valley slopes causes the upland shoulder of valleys to recede progressively.

Freshly deposited soil on this slope would be easily washed away. This aspect limits the amount of credit to be given to the pocket gopher hypothesis (Hubbs (35)). The resistance exists within the micro relief where a certain mound size is reached. This phenomenon is appreciated when viewing hummocks formed on more recent deposition, for example, Sandy, Quarternary deposits near Stidham in McIntosh County

(Figure 21).

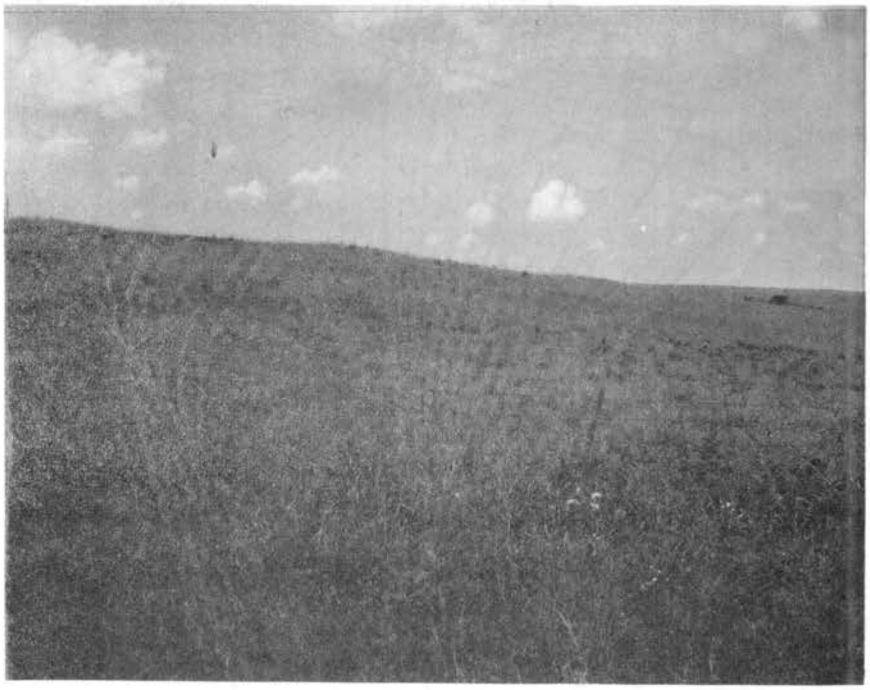


Figure 18. Mounds Occur on Moderate Slopes Where Soils are Shallow over Sandstone in the Intermound Area.

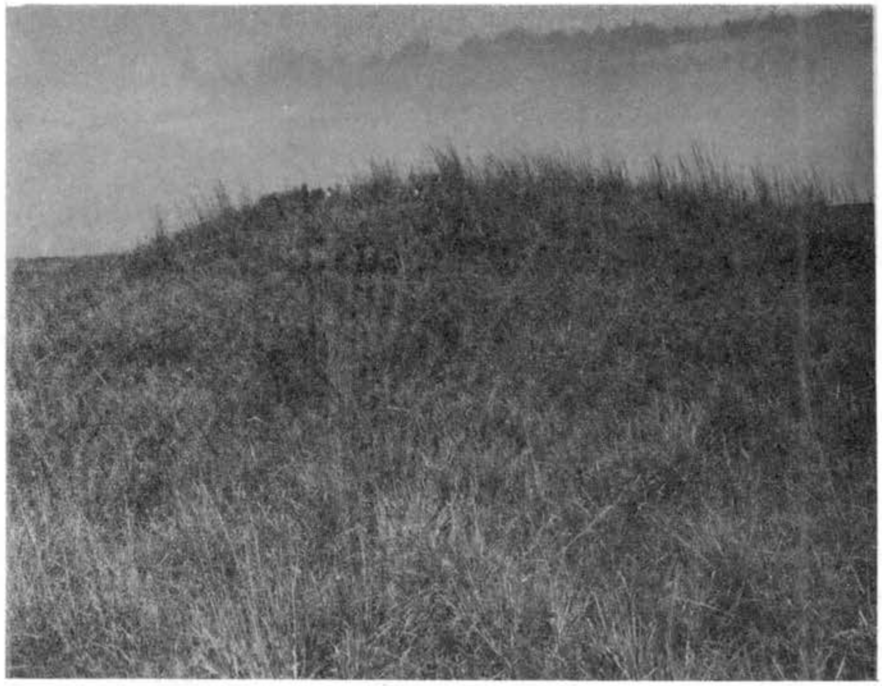


Figure 19. Mound portraying resistance to erosion where water is concentrated in the inter-mound area. It has become the largest mound of the landscape.

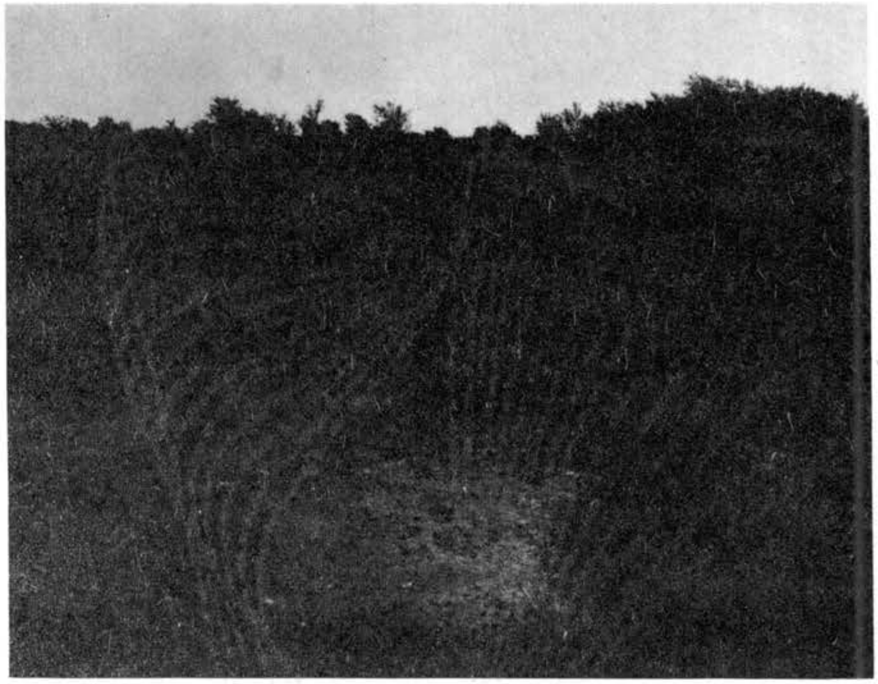


Figure 20. Erosion has left Exposures of Shale in the surrounding inter-mound area while the mound remains.

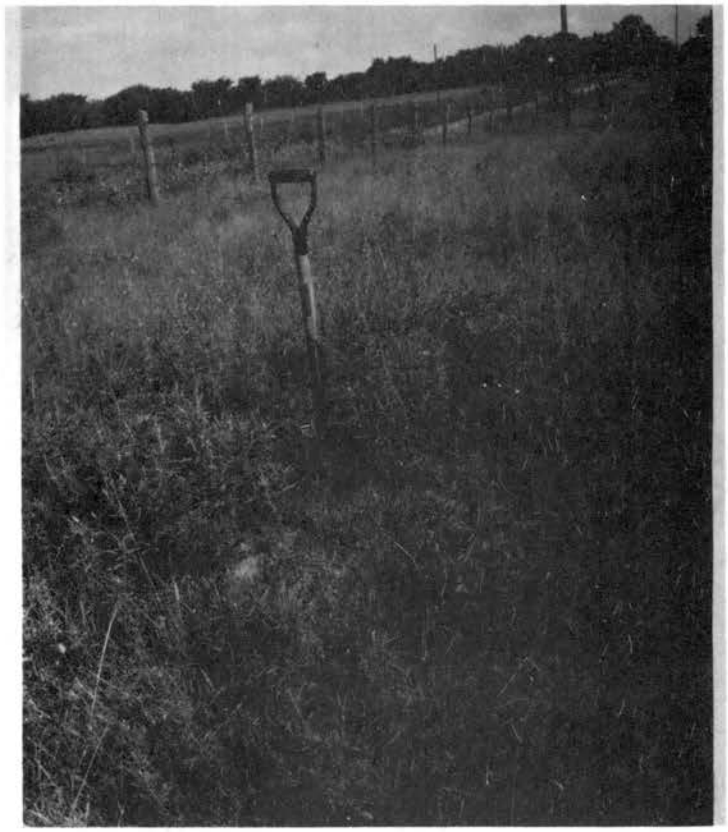


Figure 21. Sandy hummock resembling mounds near Stidham in McIntosh County. Note soil ridging by Mole in front of Spade.

These deposits contain sandy hummocks that occur in irregular sizes and shapes. The conformity of the subsoil separates these hummocks from the common type of mounds. The argillic horizon follows the contour of the hummock. Some of these, especially in the smaller ones, appear as mounds. It was observed as the landscape reaches a certain geomorphological level the interspace contains soils that are more slowly drained. This condition, like in the mounded soil sites, tends to cause the organisms to utilize the hummocks. In time this concentration may bring about the formation of a "natural mound" in equilibrium with the environment.

CHAPTER VI

INTERPRETATIONS FOR CLASSIFICATION

Biological Effects Interpreted for Soil Classification

Micro and macro features are major characteristics of the epipedon of the mounded soils. The numerous crotovinas located in the 90 degree direction of the mounded soil profile are shown in Figure 8. Crotovinas were nonexistent in the intermound pedon. Worm casts and fine channels were present in both locations but more numerous in the mounded soil pedon. Biological activity was confined to soil above the argillic horizon in both mound and intermound areas and increased with a decrease in mottling. Biological activities in the mound are probably responsible for a porous, friable epipedon with a lower bulk density than the associated intermound soil.

The transfer of soil between the A1 and A2 horizon by earthworms and rodents may affect soil weathering in two major ways. Processes of moving soil from the A2 to the A1 returns illuviated materials and the transfer of A1 to the A2 translocates minute amounts of organic material. The vertical movement of organic material would prevent the A2 from becoming subject only to mineral weathering.

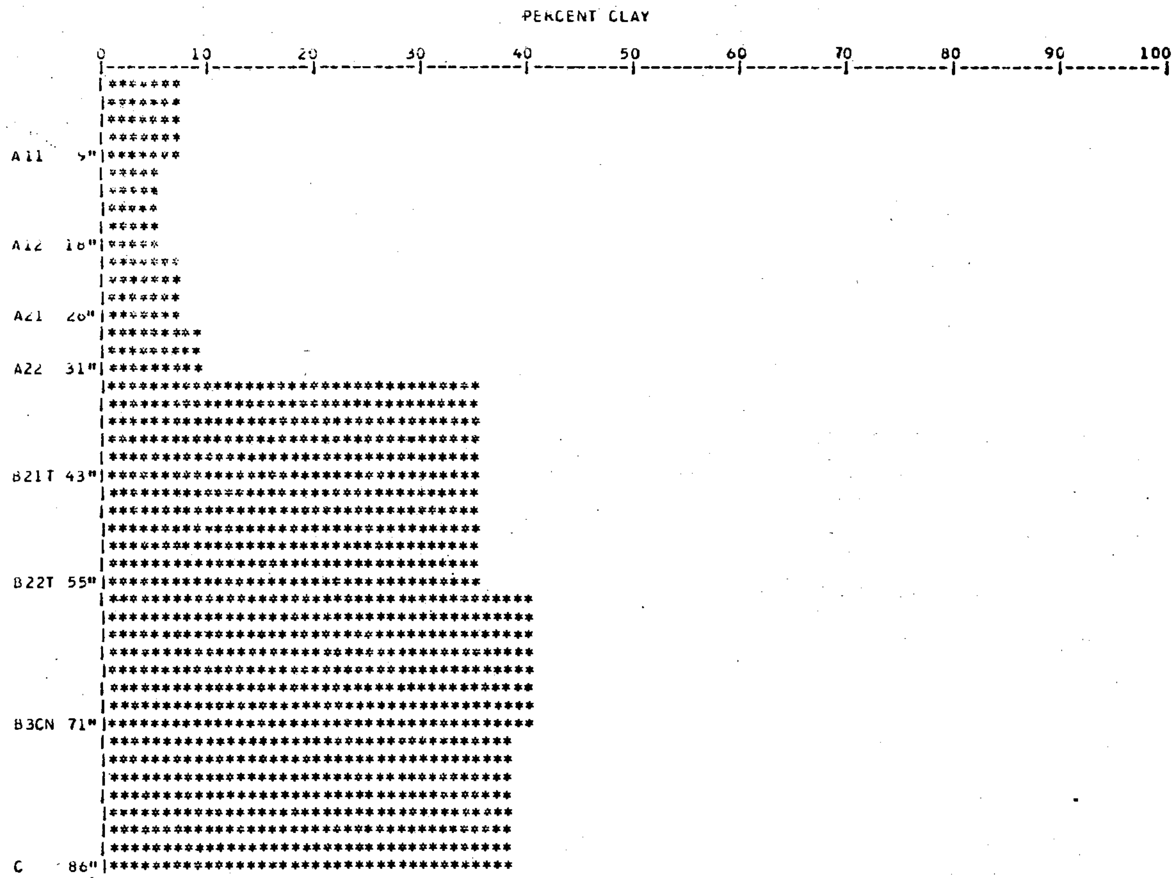
Bulk Density

The increased activity of organisms in the mound is responsible for the lower density of the A11 and A12 horizons (Figure 16). The lower density of the mounded soil epipedon accounts in part for the increased thickness of the A1 horizons (Figure 8). The consistency of the lower density of the mound soil and the magnitude in which the epipedon is altered by organisms about the mounds indicate modification that would affect soil development and classification.

Physical Measurements

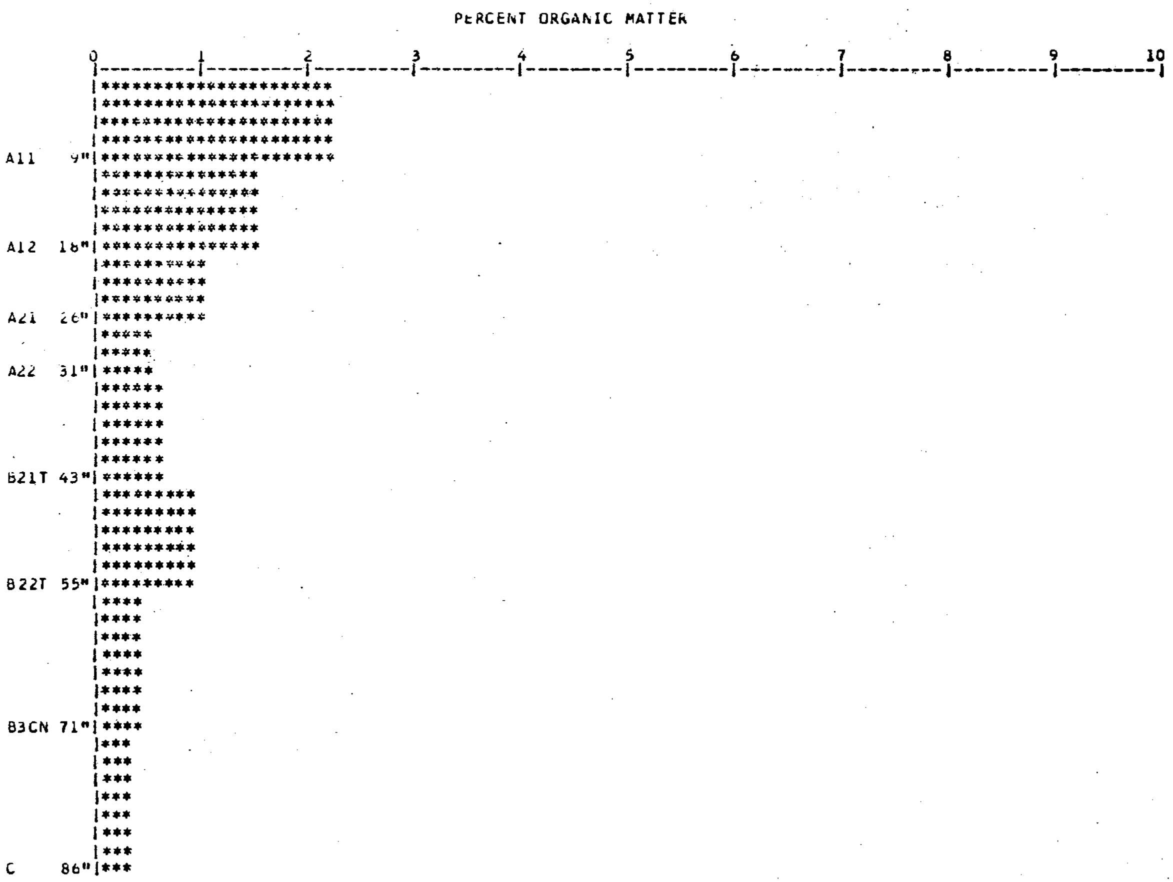
The crossectional diagrams relate the elevations and positions of soil horizons of the mounded soils to the intermound, (Figures 30 and 31). The diagrams show the A1 and A2 horizons increase in thickness toward the interior of the mound. The variation in horizon thickness of mounded soils contrasts with the smooth, relatively uniform arrangements of the horizons in the intermound area.

Significant differences in texture are found in the gradual increase in clay in the argillic horizon of the mounded soil pedon 3 and the more abrupt increase of clay in the argillic of the intermound pedon, numbered 0 (Tables IV, V and Figures 22 and 26). This characteristic suggests a different type movement of the soil plasma and may separate the classification of the two soil pedons compared. The difference in soil weathering between the mound and associated intermound also indicates that the mound has been in place for a considerable period of time. Even though the percentages of clay in the B21t in the intermound and mound vary from 36.5 to 19.4 respectively, it is of interest to note the upper boundaries of the B21t are in similar elevations in the mound and intermound as shown in Figures 30 and 31. To reach similar clay textures in the mounded soil to that in the B21t



CLAY DISTRIBUTION IN DEPTH WITHIN THE PROFILE OF TALUKA-O, MUSKOGEE COUNTY, 1970.

Figure 22. Percent Clay Distribution in Intermound Pedon O.



DISTRIBUTION OF ORGANIC MATTER WITH DEPTH IN THE PROFILE OF TALUKA-O, MUSKOGEE COUNTY, 1970.

Figure 23. Percent Organic Matter Distribution in Intermound Pedon 0

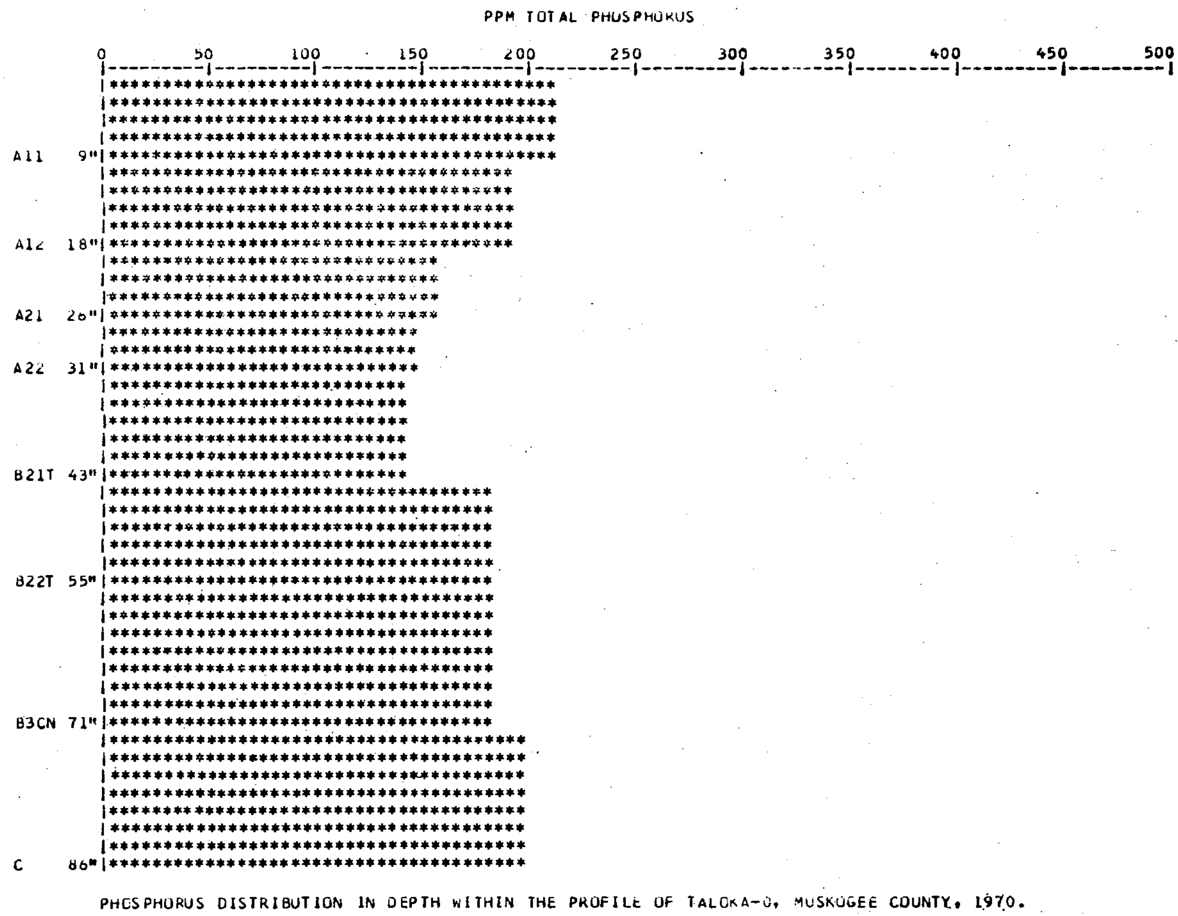


Figure 24. PPM Total Phosphorus Distribution in Intermound Pedon 0.

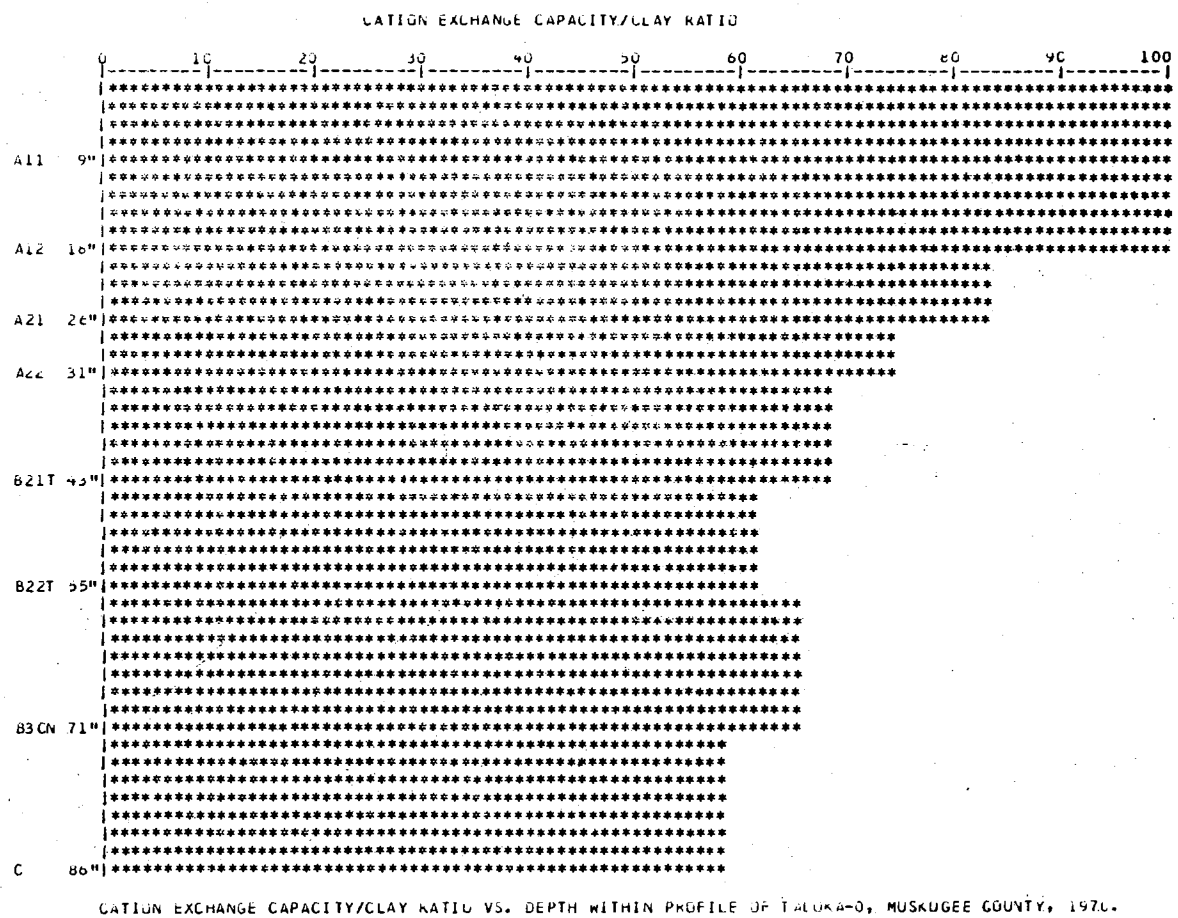
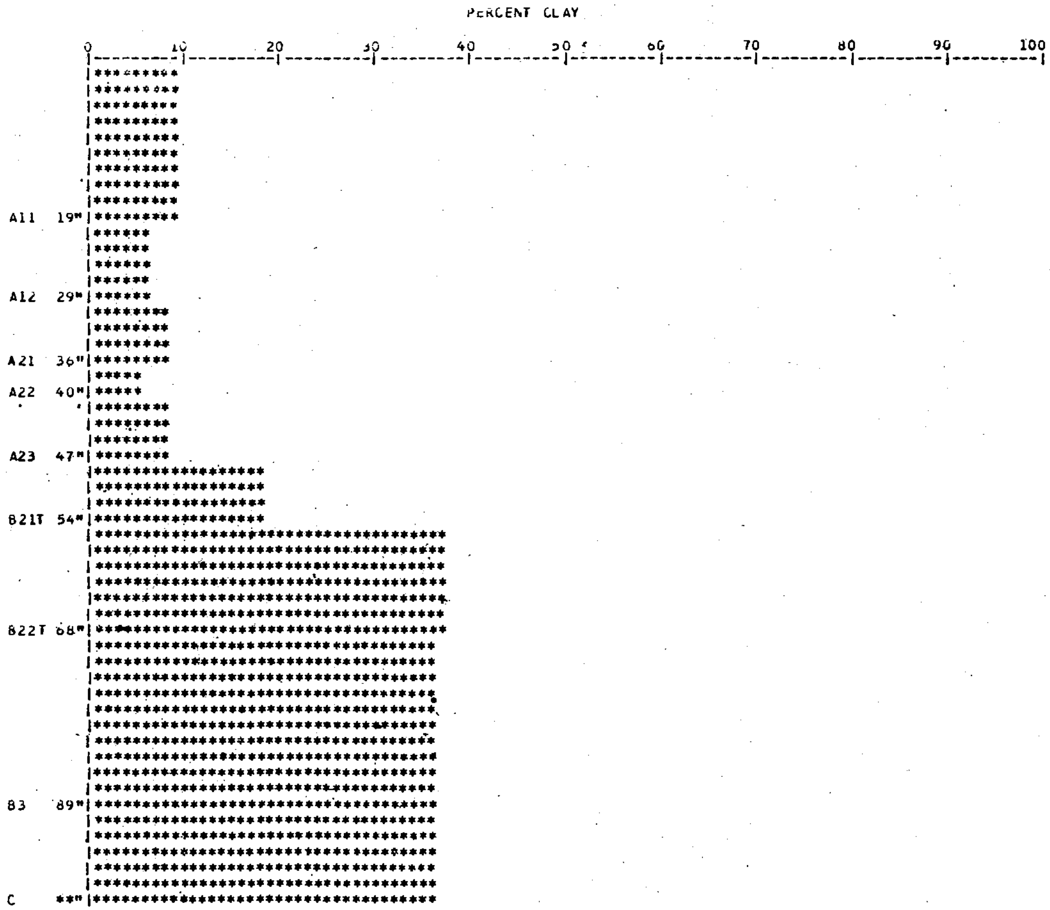
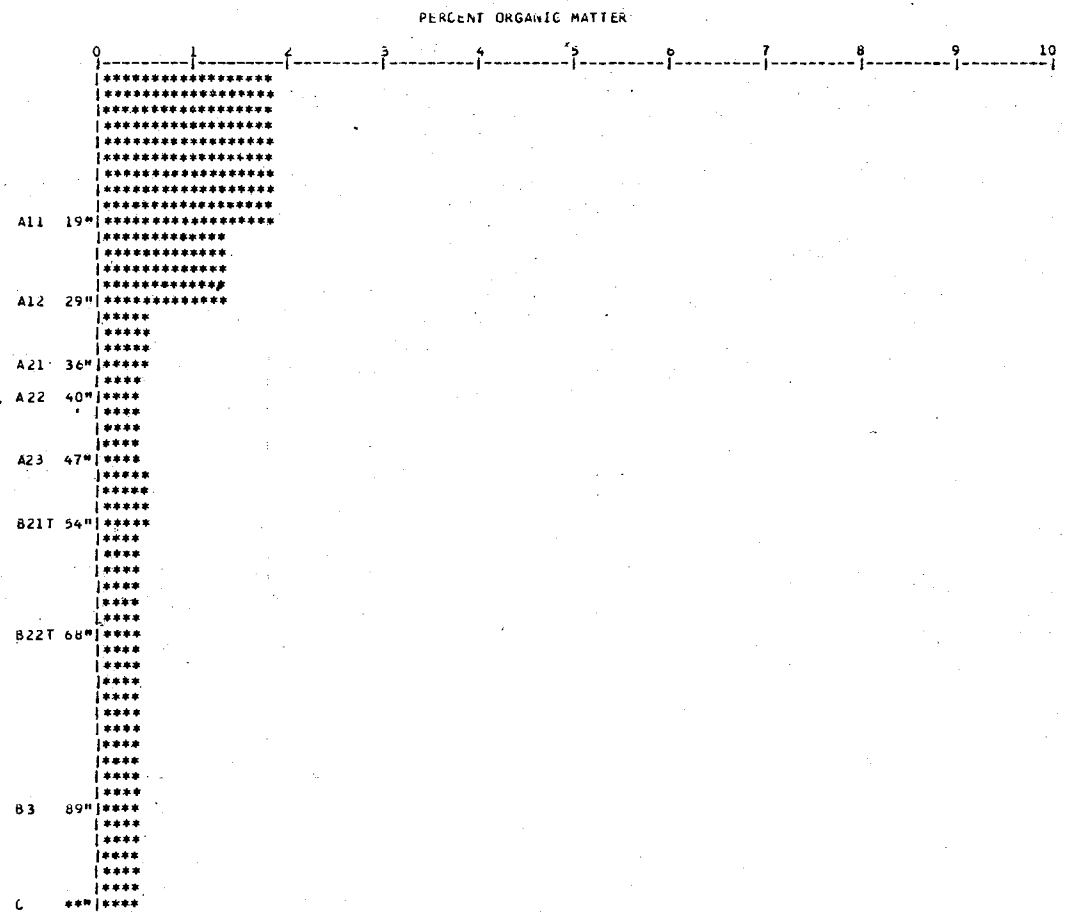


Figure 25. Cation exchange capacity/clay ratio.



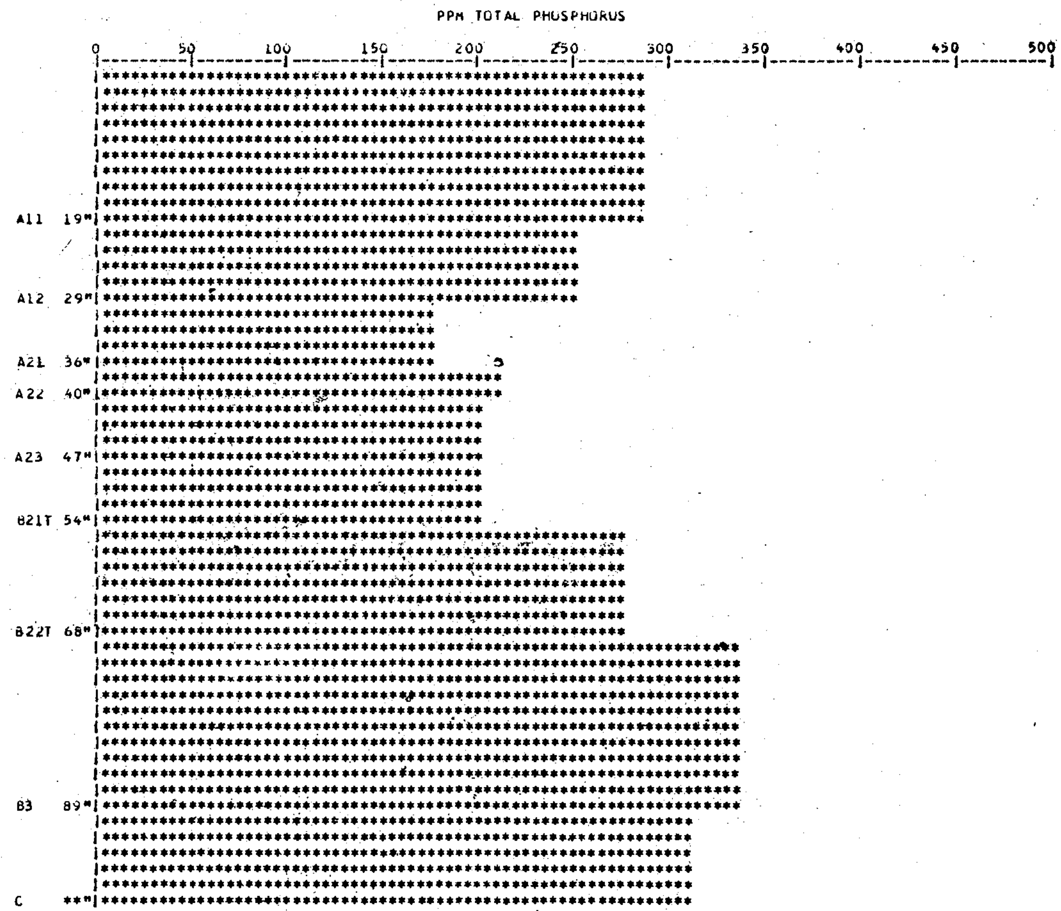
CLAY DISTRIBUTION IN DEPTH WITHIN THE PROFILE OF TALOKA-3, MUSKOGEE COUNTY, 1970.

Figure 26. Percent Clay Distribution in Mounded Soil Pedon 3.



DISTRIBUTION OF ORGANIC MATTER WITH DEPTH IN THE PROFILE OF TALUKA-3, MUSKOGEE COUNTY, 1970.

Figure 27. Percent Organic Matter Distribution in Mounded Soil Pedon 3.



PHOSPHORUS DISTRIBUTION IN DEPTH WITHIN THE PROFILE OF TALOKA-3, MUSKOGEE COUNTY, 1970.

Figure 28. PPM Total Phosphorus Distribution in Mounded Soil Pedon 3.

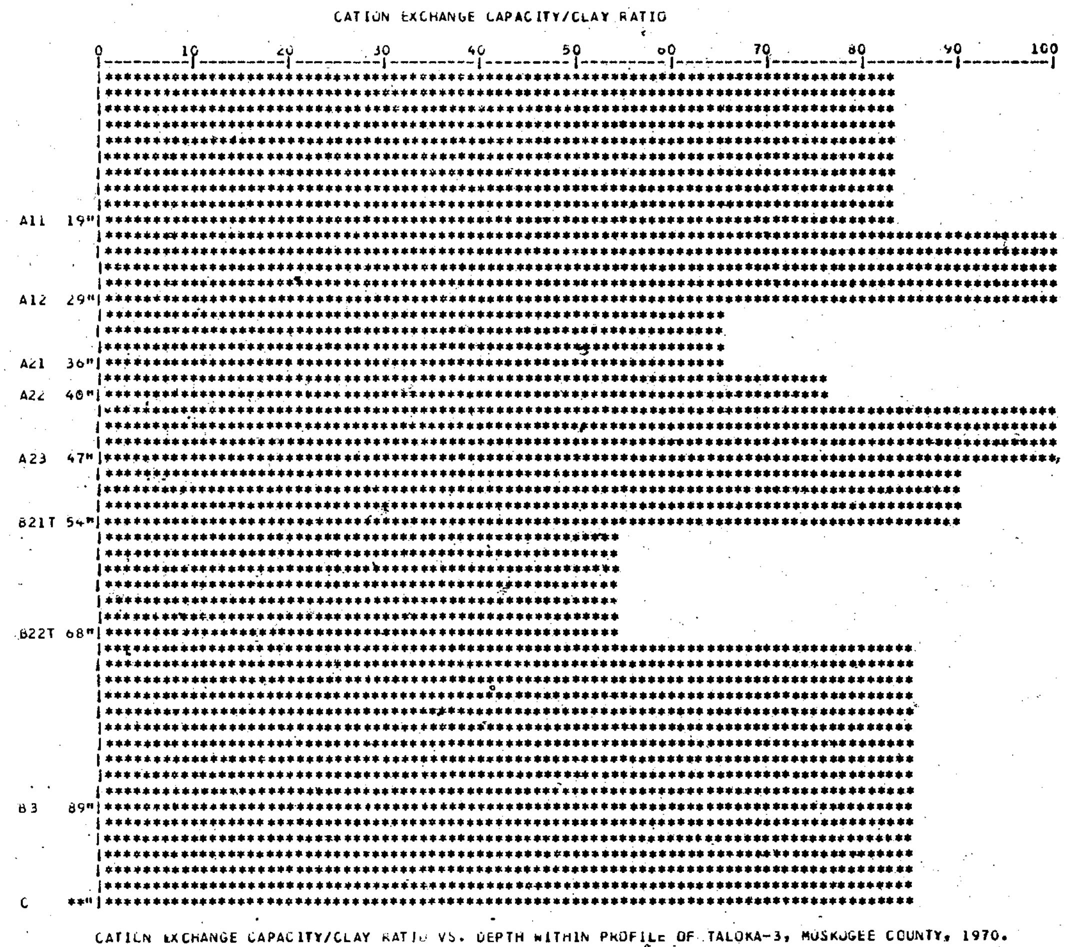


Figure 29. Cation Exchange Capacity/Clay Ratio

of the intermound would place a slight decline in the upper B2t boundary which was a characteristic reported by Ross et. al., (74) and referred to in a similar condition as "windows" under the mound by Nikiforoff (57).

Factors which may be considered in the difference in movement of soil plasma include percolation of water and biological effects. A greater volume of water movement through the intermound pedon would account for the difference in clay accumulation. However, since the mounded soils have more porous epipedons, a greater volume of water may penetrate the mound. Ross et. al., (74) found a greater accumulation of water in the mound than in the intermound soils which was attributed to the higher infiltration of the mound. A greater volume of water penetrating the mound could explain the increased thickness of the A2 horizon toward the interior of the mound. Aronow (4) reported A2 horizons present in mounds in Southeast Texas and Southwest Louisiana. Biological effects could account for restriction of the movement of soil plasma. Earthworm Lumbricus terrestris concentrations in the mound and the degradation of many buried rodents' nests with the larger volumes of forage produced on the mound are factors to consider in soil alteration. Higher base saturation in the surface horizons of the mounded soil may be significant in restricting translocation of clay in the pedon.

The translocation of silt shows a similar pattern when making a comparison between the two pedons, Tables IV and V. The silt content of the intermound pedon 0 is maximum in the A1 horizon and drops sharply in the A21 horizon. The mounded soil pedon 3 retains a high percentage of silt throughout the A2 horizons. The sand distribution is similar between the surface horizons of the two pedons with a higher percentage present in the A21 of the intermound soil. The percentage of sand in the argillic of the mounded soil pedon 3 is slightly greater than that of the intermound pedon 0.

Mounded soils and intermound soils of Site I each have argillic horizons according to differentia criteria established in the 7th Approximation (85). In the nomenclature describing the family level the mounded soils are in the fine silty family, while that of the intermound is fine clayey.

Chemical Analyses of Pedons in Site I and Interpretations

Chemical analyses of the mounded soil pedon 3 and intermound pedon 0 are shown in Tables IV and V.

Hydrogen Ion Concentration

The pH value of the soil horizon of the mounded soil shows a gradual increase from the surface down, while that of the intermound deviates with a pH of 6.0 in the A22 horizon. The mounded soils become slightly more basic in the deeper depths than the intermound soil. The reaction range for the mounded soil is strongly acid in the A11 horizon to mildly alkaline in the B3 and C horizons, while in the intermound pedon the reaction range is medium acid in the A11 to neutral in the B3 and C horizons. The pH values of the 1N Kcl-soil mixture follow the same general pattern as water pH values except that they are slightly lower. One phenomenon that cannot be easily overlooked is the slightly higher pH in the A22 horizons of the mounded soil than in the intermound. This is an aspect discussed in regard to organisms elsewhere in the report.

Organic Matter

Distribution of organic matter in soil pedons, numbers 0 and 3, are given in Figures 23 and 27. The maximum organic matter content is in the surface horizons. A second prominent accumulation is in the upper part of the argillic horizon of the intermound pedon. This illuviated accumulation is an indication of greater degradation of the pedon. Organic matter in compared horizons were greater in the pedon numbered 0 than in pedon 3, (Tables IV and V. The more porous surface soil of the mounded soil receives better aeration than that of the intermound which would account for some of the difference. Rapid degradation of plant residues would also speed recycling of nutrient elements.

Accumulations of organic matter is increased in crotovinas because of the higher concentration of residue deposited as rodent bedding or from "downwash" material from the surface. Percentages of organic matter in the A1 horizon are sufficient to qualify as a mollic epipedon, (Tables IV and V).

Extractable Cations, Cation Exchange Capacity, and Base Saturation

Extractable cations are dominated by calcium and magnesium in both pedons. Potassium is very low throughout the pedons while sodium increases with depth. The cation exchange capacity (CEC) follows closely the clay distribution of the soil pedons, (Tables IV and V). However, where cation exchange capacity/clay ratios are compared, it is somewhat different (Firgures 25 and 29). The cation exchange capacity compared to the percent clay ratio is more irregular in the mounded soil than in the intermound. This may pertain to differences in illuviated fine clays.

Sodium increased in the B2t horizons of both profiles. The exchange sodium of mounded soils, pedon 3, increased to a maximum of 2.46 meq/100 gm. in the C horizon, while that of the intermound pedon 0 increased to a maximum of 4.15 meq/100 gm. in the B3cn. The excessive sodium may be due to leaching from the surface. Hallsworth et. al., (32) placed emphasis on sodium and clay in development of "puffs" in gilgai developments in Australia. Glossic tongues that extend upward in the pedons were examined with interest. The tongues that interfinger the argillic horizon contained bleached soil that is similar in texture and color to the A2 horizon. These tongues which occurred contained many concretions and were located as shown in Figure 30. They suggest that much more swelling of clays has existed in the past than that which exists at this date. The tongues have been in place for an extended period, which is indicated by many medium size Fe-Mn concretions lining the interior of the silt textured tongues. This suggests that the fine clays moved down first, followed by the coarser, less expanding clays which formed a separation between the tongues and the albic horizon. Since the tongues do not extend into the upper part of the argillic horizon, they are not emphasized in classification. The significance of their occurrence to the origin of the mounds was ruled out since mounds are found on shallow soils over sandstone in the local region.

Percent base saturation exceeded 50 percent throughout the pedon of the mound, while that of the intermound dropped to a 49.2 in the A21. This may be significantly related to the increased number of worm casts in the A2 horizons of the mounded soils and to the effects of rodent activity in the epipedons. Movement of soil from one horizon to another, coupled with earthworm digestive effects on soil, are processes that may affect soil development (Puh (67)), Robertson (72)). The many worm casts about the mound in Site I document the higher concentration of earthworms about the mound (Pedon 3).

The difference in base saturation of the epipedon separates the pedons of the mounded soil from those of the intermound. Pedon 3 has sufficient base saturation for a mollic epipedon. Pedon 0 of the intermound has insufficient base saturation to meet the requirements of Mollisol classification as contained in the differentia criteria used in the 7th Approximation (85).

Total Phosphorus

Total phosphorus was consistently greater in the mounded soil pedon 3 than in the associated intermound pedon 0, (Tables IV and V). In pedon 3 the range was from a low of 179.2 ppm in the A21 to a high of 338.0 in the B3 horizon. The B21t of the pedon 0 contained a low of 1.45 ppm with a high of 214 ppm in the A11 horizon. Total phosphorus distribution in the intermound and mounded soil pedons are shown in Figures 24 and 28.

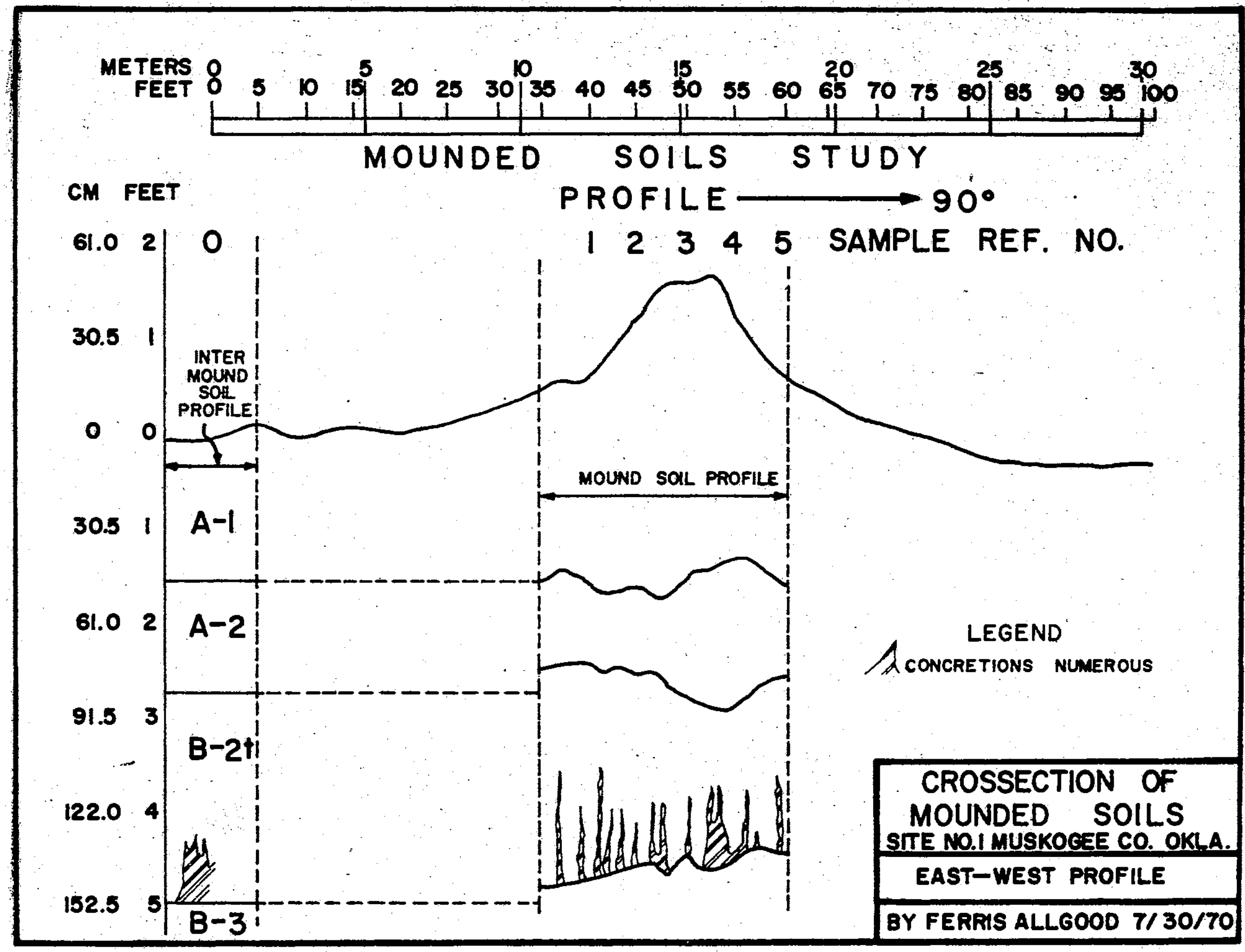


Figure 30. Crossection Profile of Intermound and Mounded Soils Site I 90° Direction.

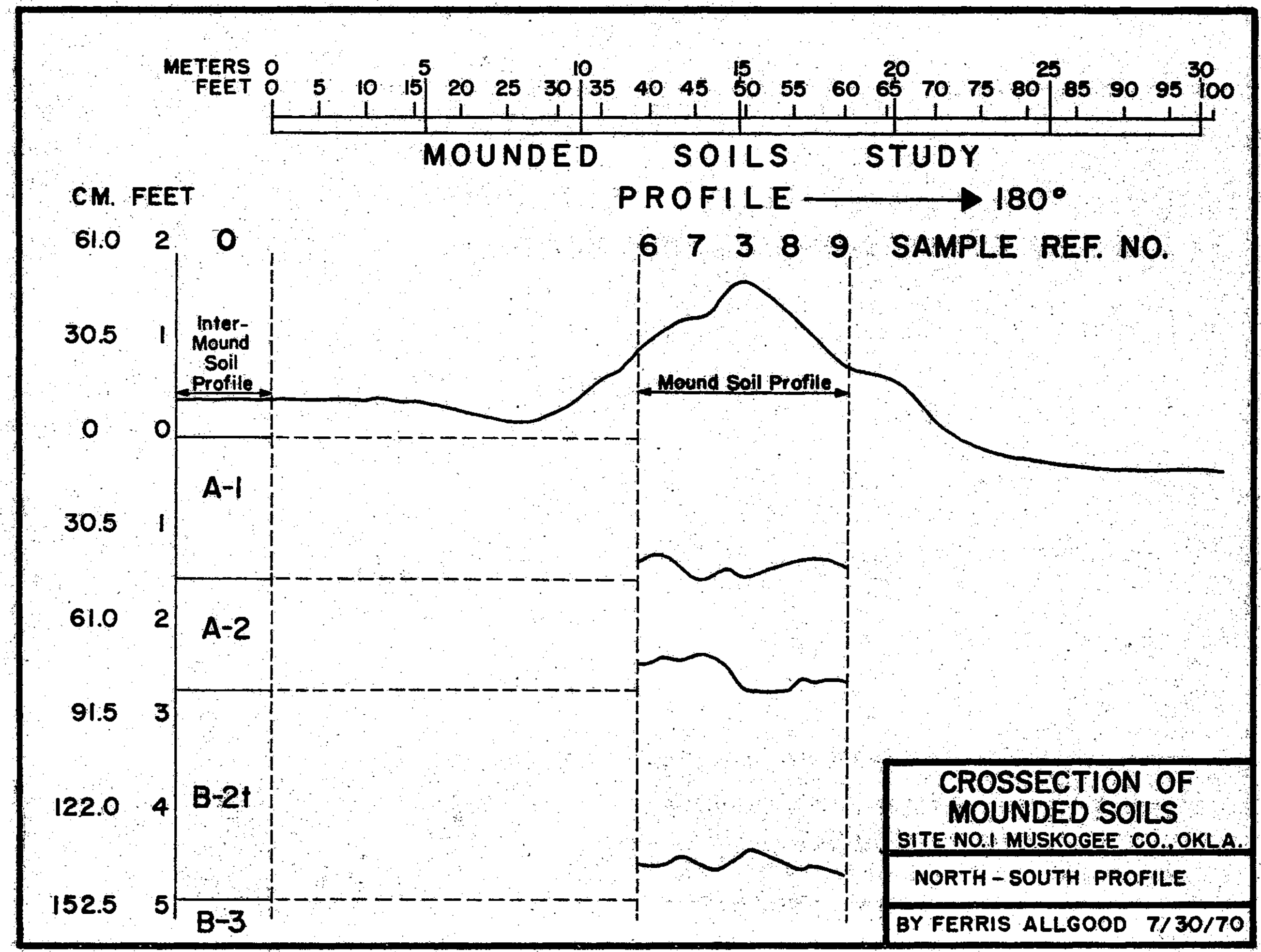


Figure 31. Crossection Profile of Intermound and Mounded Soils Site I 180^{o} Direction.

CHAPTER VII

CLASSIFICATION OF MOUNDED SOILS AND ASSOCIATED INTERMOUND SOILS OF THE STUDY AREA

SITE I

Classification

Soils occurring in Site I and in the general vicinity that is associated with mounds are classified according to the 7th Approximation Classification System currently in use, developed by the Soil Survey Staff USDA (85). Soil classification in this system emphasizes diagnostic horizons of the soil pedon. The soil pedons are classified by placing them in six categories, namely; Order, Suborder, Great Group, Subgroup, Family, and Series (Soil Survey Staff USDA 1960, 1967, and others).

Orders are the highest category in the classification system. In 1967 there were 10 orders recognized in classifying soils of the world. The differentiae used among the orders were developed with emphasis on properties that indicate the intensity of processes that develop soil horizons. Soil within a particular order contains similar characteristics indicating similar influences of soil forming processes.

Suborders are subdivisions of orders based on the characteristics that emphasize the similarity of origin. The suborder name comtains two syllables. The color associated with wetness is used to define suborders in each order in which it is found. Soil variations caused by different types of climate, vegetation, chemical or mineralogical processes are also used in determining the suborder divisions.

Great groups are subdivisions of suborders. Each great group is defined within its suborder, primarily on the presence or absence of diagnostic horizons and the arrangement of those horizons present. Where horizon arrangements do not vary within a suborder, other diagnostic properties are used, such as, base saturation, irreversible soil hardening, properties of clays, tonguing of eluvial horizons into illuvial horizons, or soil temperature.

Subgroups are subdivisions of the great groups. Subgroups indicate the variations of soils from a central concept of the great group. Varying properties are usually intergrades to other great groups, sub-orders or orders. Descriptive adjectives are used to specify particular situations exemplified in soils, truncated by rock, or extra thick surface layers.

Families are subdivisions of subgroups. Soil textures, mineralogy, reaction and temperature are the main properties used in this part of the classification with permeability, soil depth, slope, coatings and soil consistency used in some special divisions. Each family name requires one or more names. One family name consists of adjectives modifying the subgroup name.

Particle-size modifiers used in the family classes are taken from depth limits within the pedon and is referred to as the control section. Where there are no contrasting textures between the top of the argillic horizon and a depth of 1 m, the particle size modifiers are determined from the whole argillic horizon if it is less than 50 cm thick or from the upper 50 cm if the argillic horizon is more than 50 cm thick. In other soils without argillic horizons particle size modifiers or substitutes are applied from a depth of 25 cm to 1 m or to rock, if present, at a shallower depth. In soils having a depth to rock less than 36 cm, particle-size modifiers or substitutes are applied from the surface to the rock strata.

Fine-silty mixed thermic consists of a loamy particle size in the control section that has less than 15 percent of fine sand and between 18 and 35 percent clay.

Fine loamy has 15 percent or more of fine sand or coarser particles and contains 18 to 35 percent clay in the fine earth fraction in the control section. Siliceous indicates more than 90 percent of minerals present are resistant to weathering. Fine soils in the control section average more than 35 percent clay but less than 60 percent clay.

Clayey is used to indicate a clayey-skeletal in the control section which is soil containing numerous fragments, such as shale, with the fine earths filling in the pores. Shallow indicates soils have a depth of 36 cm or less over rock.

Mixed indicates that the clay fraction is not dominated by any one mineral. Thermic indicates soil temperature within a range of 15° to 20° occurs at a depth of 50 cm or at the depth of rock if thickness of soil is shallower than this depth.

Soil Series, the lowest level of classification, comprises a group of soils that is similar in its differentiating characteristics. The series name is generally a proper name of a place where the soil was first described.

Two soil orders are represented in areas containing mounded soils in the study area and both of these orders are represented in soil pedons of Site I. These are the Mollisols and Alfisols. The classification of soils in the study area associated with mounds, including those in Site I, are shown in Table VI. The following discussion explains the terms as they are used in the classification system.

Mollisols are mineral soils that have dark surface horizons (mollic epipedon) more than 25 cm thick unless the solum is thin. The soil sturcutre is sufficiently strong to maintain a horizon that is not both massive and hard or very hard when dry. Colors of both broken and crushed samples have Munsell color values darker than 3.5 when moist and 5.5 when dry and chromas of less than 3.5 when moist. Base saturation is 50 percent or more. At least 0.6 percent more organic carbon (1 percent organic matter) is present throughout the horizon.

Udoll is a suborder of Mollisols that are normally moist in the argillic or cambic horizon but may be occasionally dry.

The Hapludoll great group includes Udolls that lack argillic horizons. The subgroup Lithic Hapludolls in this study has a lithic contact consisting of sandstone at a shallow depth.

The Argiudoll great group includes Udolls that have thin argillic horizons (the ratio of clay content of A1 to the B2t horizon needs to be 1.2 or greater). The subgroup Typic Argiudolls is the major concept of this great group.

The subgroup Aquic Argiudolls has mottles near the surface indicating extended periods of wetness.

The Paleudoll great group consists of Udolls that have thick argillic horizons in which the content of clay decreases slowly with depth. Aquic Paleudolls are a subgroup that contains mottles in the

TABLE VI

CLASSIFICATION OF SOILS ASSOCIATED WITH MOUNDS IN THE GENERAL STUDY AREA

Order	Suborder	Great Group	Subgroup	Family	Series
Mollisols	Udolls	Hapludolls	Lithic Hapludolls	Loamy, siliceous thermic (mixed)	Collinsville
	Udolls	Hapludolls	Aquic Hapludolls	Clayey, mixed, thermic, shallow	Talihina
	Udolls	Argiudolls	Typic Argiudolls	Fine, loamy, siliceous, thermic	Bates
	Udolls	Argiudolls	Aquic Argiudolls	Fine, mixed, thermic	Bonham
	Udolls	Paleudolls	Aquic Paleudolls	Fine, mixed, thermic	Choteau
	Udolls	Paleudolls	Aquic Paleudolls	Fine, mixed, thermic	Dennis
	Udolls	Paleudolls	Aquic Paleudolls	Fine, mixed, thermic	Okemah
	Udolls	Paleudolls	Aquic Paleucolls[a]	Fine, silty, mixed, thermic	Mounded Soils - Site I
	Udolls	Paleudolls	Vermic Paleudolls[b]	Fine, silty mixed, thermic	Mounded Soils - Site I
	Aqualfs	Albaqualfs	Mollic Albaqualfs	Fine, mixed, thermic	Taloka
Alfisols	Aqualfs	Albaqualfs	Mollic Albaqualfs	Fine, mixed, thermic	Parsons
	Udalfs	Paleudalfs	Aquic Paleudalfs	Fine, mixed, thermic	Stigler
	Udalfs	Hapludalfs	Albaquic Hapludalfs	Fine, mixed, thermic	Intermound Soils Site I

[a]Present Soil Classification according to criteria of the 7th Approximation
[b]This is the proposed Soil Classification

upper part of the argillic horizon; at some time during the year ground water stands in the mottled horizon.

Alfisols have light colored surface soils, designated as ochric epipedons and argillic horizons with moderate base saturation with available water at least 90 days during the growing season. *Alfisols* differ from the Mollisols primarily by having less organic matter in the surface horizon and by being more highly leached of plant nutrients.

The suborder *Aqualfs* includes soils having mottled, low chromas or concretions near the surface indicating extended periods of wetness. The *Albaqualf* great group consists of *Aqualfs* that have an abrupt textural change between the eluviated and illuviated horizons. The subgroup *Mollic Albaqualfs* has a dark colored surface horizon that is less than 25 cm in thickness.

Udalfs is a suborder of the *Alfisols* that have higher chromas and less mottling indicating good drainage.

The *Paleudalf* great group includes *Alfisols* that have great thickness with a very gradual decrease in clay with depth. *Aquic Paleudalfs* comprise a subgroup that contains colors or mottling within 75 cm of the soil surface which indicates excessive wetness during the growing season.

Hapludalfs are great groups of the *Alfisols* that are not as developed to the depths of the Paleudalf great group. *Albaquic Hapludalfs* have an abrupt textural change between an eluvial horizon and the argillic horizon. They also have mottles with low chromas in the upper 25 cm of the argillic indicating long periods of excessive wetness.

Major Morphological Characteristics of Soils in Site I.

The major differences in morphological characteristics of the mound and intermound pedons are shown by the more friable and less dense surface soil of the mounded soil than the intermound soil. Degradation is less in the mound with a consistently higher base saturation throughout the pedons. Soil mottling and low chromas are not as close to the surface as in the intermound soils. The lighter colors of the A1 and low base saturation of A21, coupled with the more abrupt clay increase of the argillic horizon, separate the intermound pedon significantly from the mounded soil pedon in classification. It is apparent that the significant difference in the development of these pedons is primarily traceable to the effects of high concentration of organisms in the epipedon of the mounded soils. The location of many crotovinas and worm casts about the mounds document their concentrations about these mounded soils. The correct classification should recognize biological influences with a vermic modifier. However, at this time no vermic subroup has been included in the 7th Approximation with the appropriate great group classification.

Representative of the mound, pedon 3 is classified as a fine silty mixed, thermic Aquic Paleudoll. It is separated from all other soils classified in the vicinity of the study in the family level of classification, (Table VI. This leaves the series name undetermined.

In the intermound area of Site I, pedon numbered 0 is separated from other soils mapped in the immediate area in the Great group level of classification. It is classified as a fine, mixed, thermic

Albaquic Hapludalf. The series name is also undetermined.

From the findings in this study and by results obtained by other similar investigations of the mounds, it is evident that organisms alter the mounded soils in measurable amounts. The resulting effects establish a more highly fertile, porous surface soil with greater thickness than the associated intermound. These aspects are consistently observed and may be predicted with a high degree of certainty in the locations studied.

CHAPTER VIII

SUMMARY AND CONCLUSION

Many small mounds measuring about 15 meters in diameter and less than one meter in height are scattered intermittently through a broad area in Eastern Oklahoma. This is a part of a vast area containing mounds that extends from the southern part of Missouri to the coast of Texas. In Oklahoma the mounds are closely associated with the 101.6 cm plus rainfall belt.

Mounded soils studied in Muskogee and McIntosh Counties, Oklahoma and soil pedons were compared to the associated intermound. A mound in a 3.25ha meadow containing 46 mounds was used as the nucleus of the study (Site I). Soil pedons were described, sampled and analyzed in the laboratory. Classification of soils is according to the 7th Approximation currently in use by the Soil Survey Staff USDA.

The mounds in this study occur on landforms, old in origin, having soils with subsoils high in clay or having imperveous rock formations at a shallow depth that restrict the downward movement of water. The subsoil is not suitable for the survival of most living organisms in the soil environment because of its extreme intermittent wet condition.

Among the more numerous patrons of the area are the pocket gopher _Geomys bursarius dutcheri_, Eastern or Common Mole _Scalopus aquaticus_, skunks _Mephitis mephitis_, earthworms _Lumbricus terrestris_, and white grub _Lachnosterna fusca_. All evidences of biological activity were above the slowly and very slowly permeable argillic horizons of the soil pedons. Biological activity increased as mottling due to wetness decreased. Greater biological concentration about the mound has affected the development of the soil. The effects noted were in soil density, base saturation and clay translocation. Measured clay accumulation was more gradual into the argillic horizon beneath the mound Site I than in the intermound pedons. Increased biological activity about the mound was considered to be a prominent factor in restricting degradation and resulting in a thicker darker epipedon with less density than in the associated intermound. Where mounds were associated with shallow soils over sandstone, the pedons contained thick dark epipedons traceable to a concentration of biological activity.

Weight of vegetation production was greater on the mound than on the intermound soil in the well managed meadow containing Site I. In heavily grazed areas the reverse was observed to occur. The condition was probably caused by the preference of livestock for the vegetation growing on the mound.

Soil density was consistently found to be less in mounded soil epipedons than that of the associated intermound area. Expanding the intermound soil to densities of the mounded soils would account for a part of the altitude and size of the mound. It would be possible to form mounds of common symmetry when considering the factors responsible for the occurrence of the mound to be due to activities of organisms in their attempt to escape a high water table. Biological activity was most common in mound soils having less mottling than the intermound soil. The central location of animal nests in the mounds also indicates movement to reach the protective elevations of the mound.

The friable, less dense epipedon of the mound compared to the associated intermound has been a unanimous observation. Since it is a prominent morphological characteristic of the mounded soil of Site I, the feature deserves consideration in the soil classification system. Soils in the mound possess qualities required by differentia criteria of the 7th Approximation for a mollic epipedon. Adjacent intermound pedons lack the required qualities which by comparison indicates the significance of contributions by organisms to the mounded soils. These characteristics suggest the modifier vermic be added to the classification of the mounded soils of the site. Classification of the mounded soils, according to the present differentia criteria of the 7th Approximation, is fine silty, mixed, thermic family of Aquic Paleudolls. The associated intermound pedon is a member of the fine, mixed, thermic family of Albaquic Hapludalfs.

From observations made of the mounded soils, this study presents evidence that a reasonable composite of factors are responsible for the development of the mounded soils. This study reports evidence that suggests that the origin of the mounds and their spacing is controlled by the macro and micro biological populations of a site. These data and conclusions would suggest an equilibrium with the environment over a long period of time. It is probable as the smallest "mole hill" or pocket gopher excavation is formed, micro life increases in covered and decaying vegetation. Soon this organic material is utilized by the earthworm. The site also becomes choice location for the mole since the earthworm is a major portion of the diet of the mole. The pocket gopher uses the mound for the more nutritious plant roots and as a safe site for delivery of its young. By the gopher's system of digging; by downwash from the surface and contributions of many other forms of organisms collecting in the mounds, a more fertile organic soil is developed to a slightly greater depth in the earth than in the intermound area. By these processes biological activity thrives and is able to sustain a higher and better habitat above the changing water table.

Sheet erosion in the intermound areas also contributes to an increase in size of the mound by removing soil from the fringes of the mound and from the interspace. Lower soil density of the mounds caused by rodent activity and excessive runoff between the mounds are attributes that affect the size of the mounds.

LITERATURE CITED

(1) Arkley, R. J., 1948. The Mima mounds. Sci. Monthly. 66: 174-176.

(2) Arkley, R. J., and H. C. Brown. 1954. The origin of Mima mound hogwallow microrelief in the far Western states. Proc. Soil Sci. Soc. Amer. 18: 195-199.

(3) Arlton, A. V., 1936. An ecological study of the mole. Jour. Mamm. 17: 349-371.

(4) Aronow, Saul, 1962. Internal characteristics of pimple (prairies) mounds in southeast Texas and southwest Louisiana. (Abstract): Geol. Soc. America Spec. Paper 73, Abstracts for 1962. p. 106.

(5) Barnes, G. W., 1879. The hillocks or mound formations of San Diego, California. Am. Naturalist. 13: 565-571.

(6) Bell, Walton, 1961. Surface geology of the Muskogee area, Muskogee, Oklahoma. "Shale Shaker" Oklahoma City Geol. Soc. 12: 2-21.

(7) Bellis, S. E. and A. Muir, 1956. Gilgai phenomena in tropical black clays of Kenya. Journ. Soil Sci. 7:1. p. 1-9.

(8) Bernard, Hugh A., and Rufus LeBlanc. 1965. Resume of the Quaternary Geology of Northwestern Gulf of Mexico Province. The Quaternary of the U. S. 137-185.

(9) Bik, M. J. J., 1968. Morphoclimatic observations on prairie mounds. Zeitschrift fur Geomorphologie. 12: 409-489.

(10) Branner, J. C., 1905. Natural mounds or hogwallows. Sci. N. Ser., 21: 535. 514-516.

(11) Branson, C. C., 1966. Oklahoma Geology Notes. 26:11. 262-263.

(12) Breckenridge, W. J. and J. R. Tester. 1961. Growth, local movement and hibernation of the Manitoba toad, <u>Bufo hemiophrys</u>. Ecology. 42: 637-646.

(13) Bretz, J. H. 1928. Channeled scablands of Eastern Washington. Geograph Rev. 18: 446-477.

(14) Brewer, Roy. 1964. Fabric and mineral analysis of soils. John Wiley and Sons, Inc., New York. London. Sydney.

(15) Buechner, H. K. 1942. Interrelationship between the pocket gopher and land use. Jour. Mamm. 23: 346-348.

(16) Campbell, M. R. 1906. Natural Mounds. Journ. Geol. 14: 708-717.

(17) Clendenin, W. W. 1896. Preliminary report upon the Florida parishes of east Louisiana and the bluff prairie and hill lands of Southwest Louisians. Bull. Louisiana State Exp. Sta. Geol. and Agr. pt. 3: 180.

(18) Criddle, S. 1930. The prairie pocket gopher, Thomomys talpoides rufescens. Jour. Mamm. 11: 26. 265-280.

(19) Dalquest, W. W. and D. R. Orcutt. 1942. The biology of the least shrew mole, Neurotrichus gibsii minor. American Midland Naturalist. 27: 387-401.

(20) Dalquest, W. W. and V. B. Scheffer. 1942. The origin of the Mima mounds of Western Washington. Jour. Geology. 50: 68-84.

(21) Darwin, C. R. 1881. The formation of the vegetable mound through the action of worms. John Murry and Co. London.

(22) Day, P. R. 1953. Confirmation of hydrometer theory. Soil Science. 75: 181-186.

(23) English, P. F. 1932. Some habits of the pocket gopher, Geomys breviceps breviceps. Jour. Mamm. 13: 126-131.

(24) Farnsworth, P. J. 1906. On the origin of the small mounds of the lower Mississippi Valley and Texas. Ibid. 589. 583-584.

(25) Featherman, A. 1872. Dune theory. 3d. Ann. Rept. Botonical Survey Southwest and Northwest Louisiana. 106-107.

(26) Fenneman, N. M. 1931. Physiography of Eastern United States. McGraw Hill Book Co., New York: 714 p.

(27) Freeman, O. W. 1926. Scabland mounds of Eastern Washington. Science News Ser. 64:450-451.

(28) ____________ 1932. Origin and economic value of the scabland mounds of EAstern Washington. Northwest Sci. 6: 37-40.

(29) Gangmark, H. A. 1961. Theory on development of mounds near Red Bluff, Calif. Fishery Bulletin of the Fish and Wildlife Service. U. S. Dept. of the Interior. 63:1. 213-219.

(30) Glass, B. P. 1952. Ecological factors affecting distribution and speciation of pocket gophers in Oklahoma. Ph.D. Dissertation, Oklahoma State University, Stillwater, Oklahoma. 78 p.

(31) Gray, Fenton, and H. M. Galloway. 1959. Soils of Oklahoma. Misc. Publ. Mp 56. Oklahoma State University.

(32) Hallsworth, E. G., Gwen K. Robertson, and F. R. Gibbons. 1955. Studies in Pedogenesis in New South Wales VII. The (gilgai) Soils. Jour. Soil Sci. 6: 1-31.

(33) Hilgard, E. W. 1905. The prairie mounds of Louisiana. Ibid. 536. (April 7, 1905): 551-552.

(34) Holdredge, C. P., and H. B. Wood. 1947. Mound and depression topography of the Central Valley of California and other areas (Abstract). Geol. Soc. America Bull. 58, pt. 2: 1253-1254.

(35) Hubbs, C. L. 1957. Recent climatic history in California and adjacent areas. Recent Research in climatology, Institution of oceanography. 8: 10-22.

(36) Joffe, J. S. 2949. Pedology, 2nd Ed., Publication New Brunswick, New Jersey.

(37) Knechtel, M. M. 1949. Geology and coal and natural gas resources of Northern LeFlore County Oklahoma. Okla. Geol. Sur. Bull. 68: 10-11.

(38) ______________ 1952. Pimpled plains of Eastern Oklahoma. Geology Soc. Amer. Bull. 63: 689-700.

(39) Koons, F. C. 1948. The sand mounds of Louisiana and Texas. Sci. Monthly. 66: 297-300.

(40) Krinitzsky, E. L. 1949. Origin of pimple mounds. Amer. Jour. Sci. 247: 706-714.

(41) LeConte, Joseph. 1874. On the great lava-flood of the Northwest: on the structure and age of the Cascade Mountains. Amer. Jour. Sci. 3d. Ser. 7: 167-180, 259-261, 362-367.

(42) ______________ 1877. Hog wallows or prairie mounds (California and Oregon) Nature. 15: 530-531.

(43) Lunt, H. A., and G. M. Jacobson. 1944. The chemical composition of earthworm casts. Soil Science 58: (5) Nov. 367-375.

(44) Malde, H. E. 1961. Pattern ground of possible solifluction origin at low altitude in the Western Snake River Plain, Idaho. Short papers in the geologic and hydrologic science. U.S. Geol. Sur. Prof. Paper, 424 B: B170-B173.

(45) ____________ 1964. Patterned ground in the Western Snake River Plain Idaho and its possible cold climate origin. Bull. of the Geol. Soc. of Amer. 75: 191-208.

(46) Masson, P. H. 1949. Circular structures in Northeastern California. Calif. Div. Mines. Bull. 151: 61-71.

(47) Meeks, R. A. 1957. The geology of the Onapa-Council Hill Area, Muskogee and McIntosh Counties Oklahoma. Masters Thesis. Oklahoma University.

(48) Melton, F. A. 1929. Natural mounds of Northeastern Texas, Southern Arkansas and Northern Louisiana. Okla. Acad. Sci. Proc. 19: Univ Bull. n.s. 456: 110-130.

(49) ____________ 1935. Vegetation and soil mounds. Geog. Rev. 25: No. 3: 430-433.

(50) ____________ 1954. Natural mounds of Northeastern Texas, Southern Arkansas, and Northern Louisiana. The Hopper, Dedicated to Oklahoma's Development (Okla. Geol. Sur., Norman) 14: 87-121.

(51) Miller, M. A. 1957. Burrows of the Sacramento Valley pocket gopher in flood-irrigation alfalfa fields. Hilgardia 26: 431-452.

(52) Miller, R. S. and H. E. Bond. 1960. The summer burrowing activity of pocket gophers. Journ. Mamm. 41: 469-475.

(53) Nakamura, Yoshio. 1968. Studies on the ecology of terrestrial Oligochaeta. Appl. Entomol. Zool. 3: (27): 89-95.

(54) Neff, Everett R. 1961. Subsurface geology of McIntosh County Oklahoma. Masters Thesis. University of Oklahoma.

(55) Newcomb, 1940. Hypothesis for the periglacial "fissure polygon" origin of the Tenino Mounds, Thurston County, Washington. Geol. News-Letter of Geol. Soc. of Oregon County: 6: 182.

(56) Newcomb, R. C. 1952. Origin of Mima mounds, Thurston County Region, Washington. Journ. of Geol. 60: 461-472.

(57) Nikiforoff, C. C. 1941. Hardpan and microrelief in certain soil complexes of California. U.S. Dept. Agr. Tech. Bull. 745: 29.

(58) Olmsted, R. K. 1963. Silt mounds of Missoula flood surface. Geol. Soc. Amer. Bull. 74: 47-54.

(59) Palmer, Ralph S. 1954. The Mammal Guide, Doubleday & Co., Inc. Garden City, N. Y. 198-203.

(60) Parker, G. H., and H. M. Parskley. 1911. The reaction of the earthworm to dry and to moist surface. Exp. Zool. 11: 361-363.

(61) Peech, Michael, R. L. Corvan, and J. H. Baker. 1962. A critical study of the $BaCI_2$-triethanolamine and ammonium acetate method for determining the exchangeable H^+ content of soils. Soil Sci. Soc. Amer. Proc. 26: 37-40.

(62) Pewe, T. L. 1948. Origin of the Mima mounds. Sci. Mo. 66: 293-296.

(63) Piper, C. V. 1905. The basalt mounds of the Columbia lava. Sci. News Ser. 21: 824-825.

(64) Price, W. A. 1949. Pocket gophers as architects of Mima (pimple) mounds of the Western United States. Texas Journ. Sci. 1: 1-17.

(65) __________ 1950. Origin of pimple mounds. Amer. Journ. Sci. 248: 355-360.

(66) Prosser, C. L. 1935. Impulses in the segmental nerves of earthworms. F. exp. Biol. 12: 95-104.

(67) Puh, P. C. 1941. Beneficial influence of earthworms on some chemical properties of the soil. Soil Sci. Soc. China, Biol. Lab. Contrib. Zool. Ser. 15: 147-155. (Cited in Lunt, H. A., and H. G. M. Jacobson 1944. The chemical composition of earthworm casts. Soil Sci. 58: (5) Nov. 367-375.

(68) Purdue, A. H. 1905. Concerning the natural mounds. Ibid. 543: 823-824.

(69) Retzer, J. L. 1946. Morphology and origin of some California mounds. Soil Sci. Soc. Amer. Proc. 10: 360-367.

(70) Reynierse, J. H., and S. C. Ratner, 1964. Acquisition and extinction in the earthworm, _Lumbricus terrestris_. Psychol. Rec. 14(3): 383-387.

(71) Ritchie, A. M. 1963. The erosional origin of the Mima mounds of Southwest Washington. Jour. Geology. 61: 41-50.

(72) Robertson, J. D. 1936. The function of the calciferous glands of earthworms. Jour. Exp. Biol. 13:279-297.

(73) Roscoe, J. H. 1953. Antarctica. Air Force Manual 200-30. Washington, D. C. Dept. of the Air Force. pp. 171, 123,124.

(74) Ross, B. A., J. R. Tester, and W. J. Breckenridge. 1968. Ecology of Mima-type mounds in Northwestern Minnesota. Ecology. 49: 172-177.

(75) Ruhe, R. V. 1959. Stone lines in soils. Soil Sci. 87(4): 223-231.

(76) Scheffer, V. B. 1947. The mystery of the Mima mounds. Sci. Monthly. 65(5): 283-294.

(77) ____________ 1958. Do fossorial rodents originate Mima-type microreflief? The American Midland Naturalist. 59(2): 505-510. April, 1958.

(78) Schollenberger, C. J. 1931. Determination of organic matter. Soil Sci. 31: 483-496.

(79) Shaw, C. F. 1928. Profile development and the relationship of soils in California. Lst Intern, Cong. Soil Sci. Proc. and Papers. 4: 291-317.

(80) Shelton, W. R., and H. J. Harper. 1941. A rapid method for the determination of total phosphorus in soils and plant material. Iowa St. College Jour. of Sci. 15: 403.

(81) Shepherd, E. M. 1905. The New Madrid earthquake. Jour. Geol. 13: 45-62.

(82) Silverberges, Robert. 1969. American Heritage. 61-63; 90-95.

(83) Spellmon, W. J. 1905. Natural mounds. Ibid. 538-632.

(84) Soil Conservation Service USDA 1667, Soil Survey Laboratory methods and Procedures for collecting Soil Samples. Soil Survey Investigative Report. (1) 1-49.

(85) Soil Survey Staff, SCS, USDA. 1960-1967. Soil Classification. A comprehensive soil classification system, 7th Approximation and Supplement. Dec., 1971.

(86) Tester, J. R., and W. J. Breckenridge. 1964. Winter behavior pattern of the Manitoba toad, Bufo hemiophrys in Northwest Minnesota. Annales Academiae Scientiarum Fennicae. Series A IV Biologica. 71: 423-431.

(87) USDA Handbook No. 60. Saline and alkali Soils. p. 94.

(88) Veatch, A. C. 1905. The question of the origin of the natural mounds of Louisiana, Arkansas, and Texas. Science. 21; 310-311; 350-351.

(89) ____________ 1906. Geology and underground water resources of Northern Louisiana and Southern Arkansas. U.S. Geol. Survey Prof. Paper. 46: 16: 55-59.

(90) ____________ 1906. On the human origin of the small mounds of the lower Miss. Valley and Texas. Ibid. XXIII(575) Jan. 5. 34-36.

(91) Washburn, A. L. 1956. Classification of patterned ground and review of suggested origins. Geol. Soc. Amer. Bull. 67: 825-866.

(92) Waters, A. C., and C. W. Flagler. 1929. Origin of the small mounds on the Columbia River Plateau. Amer. Jour. Sci., 5th series. 18: 209-224.

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