Maine Geological Survey

John R. Rand, State Geologist

GLACIAL LAKE AND GLACIAL MARINE CLAYS of the Farmington Area, Maine

Origin and Possible Use as Lightweight Aggregate

by

Dabney W. Caldwell

Special Geologic Studies Series #3

Department of Economic Development

Augusta, Maine

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GLACIAL LAKE AND GLACIAL MARINE CLAYS OF THE FARMINGTON AREA, MAINE

Origin and Possible Use as Lightweight Aggregate

by

Dabney W. Caldwell
Department of Geology
Wellesley College
Wellesley, Massachusetts

Introduction

Several studies by the Maine Geological Survey have served to outline the general distribution of glacial-marine clay deposits in coastal and central Maine (Trefethen, 1947; Goldthwait, 1949 and 1951). The results of these studies provide an excellent source of information concerning the location of the clay deposits, their relation to other sedimentary units, estimated thicknesses of clay deposits, and many details of the origin of certain features found in the clay deposits.

Because these previous studies were of a reconnaissance nature, no definite conclusions were reached by their authors concerning such problems as the relation between clay deposition and glaciation, the distinction between marine and fresh water clay deposits, and many observed variations in the thickness of certain clay deposits.

The purpose of this paper is to present the details of the stratigraphy of clay deposits in a small area which may be considered as typical of much of south-central Maine. The Sandy River area was chosen because the writer was familiar with many of the clay deposits in the area and had some knowledge of the glacial geology from previous studies (Caldwell, 1953). If the conclusions arising from the present detailed study and presented in this paper are correct, then several questions raised during the previous studies are answered. The stratigraphy of these and similar clay

deposits may become an important tool in the outlining of the late Pleistocene history of Maine.

The results of chemical and physical tests performed on the many samples of clay collected in the Sandy River area indicate that Maine possesses an extensive and potentially valuable resource in these and similar clay deposits in southern Maine as a source of raw material in the production of lightweight aggregate for lightweight concrete.

This study was sponsored by the Maine Geological Survey. The writer wishes to express his appreciation for the generous assistance he received in the preparation of this paper. John R. Rand and Robert G. Doyle of the Maine Geological Survey proved to be of invaluable aid during the firing of the clay samples and offered many suggestions as to the procedure and control of the firing experiments. Donald H. Direnzo of Topsham, Maine, was able, despite many difficulties, to keep the furnace used in firing the clays in good running condition. The furnace was provided by Topsham Feldspar Company, Emery W. Booker, President. Arthur L. Bloom, of Yale University, provided the writer with invaluable information concerning clay stratigraphy in southern Maine. Frederick Boyce, of the Soils Laboratory, Maine State Highway Commission, made available to the writer much valuable stratigraphic information collected by his organization and also provided him with some clay samples. Finally, the writer wishes to thank Mrs. Margaret Steele and Miss Norma H. Winship, who typed the manuscript.

Geographic and geologic setting

LOCATION – The area of this study is in west-central Maine, in southeastern Franklin County and southwestern Somerset County. The valley of the Sandy River and those of its principal tributaries between Strong and Anson comprise most of the area considered in detail. The location of the Sandy River area is shown in Figure 1.

Aerial photo coverage flown by the James W. Sewall Co., Old Town, for the Maine Forestry Department is complete for the area. The Farmington and Norridgewock quadrangles cover most of the area, and minor portions are shown on the Kingfield, Livermore, and Anson quadrangles.

ACCESS – Access to the Sandy River may be gained from a series of roads which more or less parallel both sides of the river. There are a few bridges which cross the river. The location of U. S. Route 2, the principal highway through much of the area under consideration, and various state highways and other roads is shown in Plate 1.

TOPOGRAPHY AND DRAINAGE – The Sandy River drains the Blue Mountains, the geographical extension of the White Mountains, and the belt of foothills to the south and east of the Blue Mountains. Between Strong and Anson (see Plate 1) the maximum relief, about 2000′, is in the vicinity of Strong. South and east of Strong the relief generally decreases to less than 200 feet in the Norridgewock area.

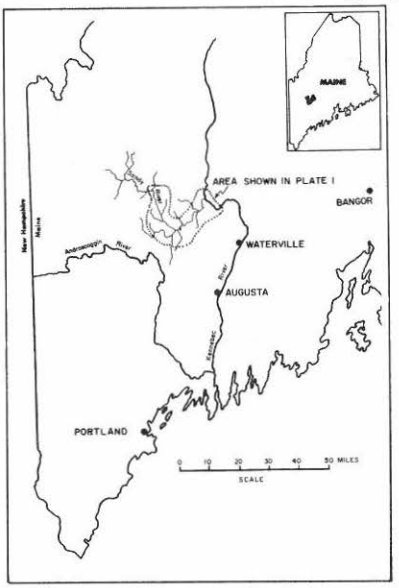

FIGURE 1. Map showing location of Sandy River – Farmington Area, Maine.

The Sandy River is tributary to the Kennebec River a few miles south of Anson. The average mean annual discharge recorded at Mercer, the only gaging station on the Sandy River, during the years 1928-1950 is 874 cubic feet per second, and the maximum discharge of 38,600 cfs was recorded during the March floods of 1936 (U. S. Geological Survey Water Supply Paper 1301).

BEDROCK GEOLOGY – The published information concerning the bedrock geology of the Sandy River area consists of a reconnaissance survey by Allen and Pratt (1949) and a detailed study of the northwest quarter of the Farmington quadrangle by Boone (1955). The bedrock in the area according to these authors consists of phyllite, quartzite, schist, and lime silicate gneiss. The general structure is one of north-east trending folds with vertical or steep northerly dips. Small intrusive bodies of granite and granodiorite occur in the Chesterville-New Sharon area and in the vicinity of Allens Mills. According to Boone (1955, p. 62)

the metasediments are probably pre-middle Devonian and the igneous rocks middle to late Devonian (Acadian) in age.

Collection of samples

Natural exposures of clay occur principally along stream banks from which samples of the various stratigraphic units exposed were taken. Clay is also exposed in road cuts, gravel pits, and other excavations in the area, from which several clay samples were taken. The majority of samples discussed in this paper consist of the cuttings of a hand driven auger, with which samples were taken from depths ranging from a few inches to about 30 feet below the ground surface. The location of these sampling localities and other localities where stratigraphic notes were taken are shown on Plate 3.

In natural or artificial exposures it was possible to obtain uncontaminated samples of clay by clearing the exposures of any slump or wash deposits. Depending on the information desired and the stratigraphy exposed, channel samples of all or part of the material in a particular exposure were obtained, each sample consisting of about 5 pounds of clay.

The cuttings retained on the auger were usually contaminated in the uncased holes, and the outer surface of the cuttings was discarded in an attempt to reduce the contamination. From most clays sampled, it was possible to obtain a 5-pound sample from the cuttings of about 2 feet of penetration by the auger.

Each sample was preserved for laboratory analysis in airtight containers in order that the natural water content of the clay could be retained. The procedures and results of the various laboratory tests performed on the clay samples are discussed in a following section of this paper.

Stratigraphy of the clay

The distribution of the clay in the Sandy River valley is known from the various types of exposures described above and from the logs of borings made by the Soils Laboratory, Maine State Highway Commission. In what is hereafter called the upper Sandy River valley, that is, the valley upstream from New Sharon (see Plate 1), the clay underlies a deposit of sand and silt which ranges from a few feet to more than 30 feet in thickness. In the

lower Sandy River valley, downstream from New Sharon, the clay is in many places exposed at the surface and is nowhere covered by more than a few feet of sand.

CLAY DEPOSITS IN THE UPPER SANDY RIVER VALLEY – Detailed descriptions of the stratigraphy exposed or inferred from the logs of auger drilling and wash borings at several places in the upper Sandy River valley will serve to illustrate the general distribution of clay and its relation to other stratigraphic units.

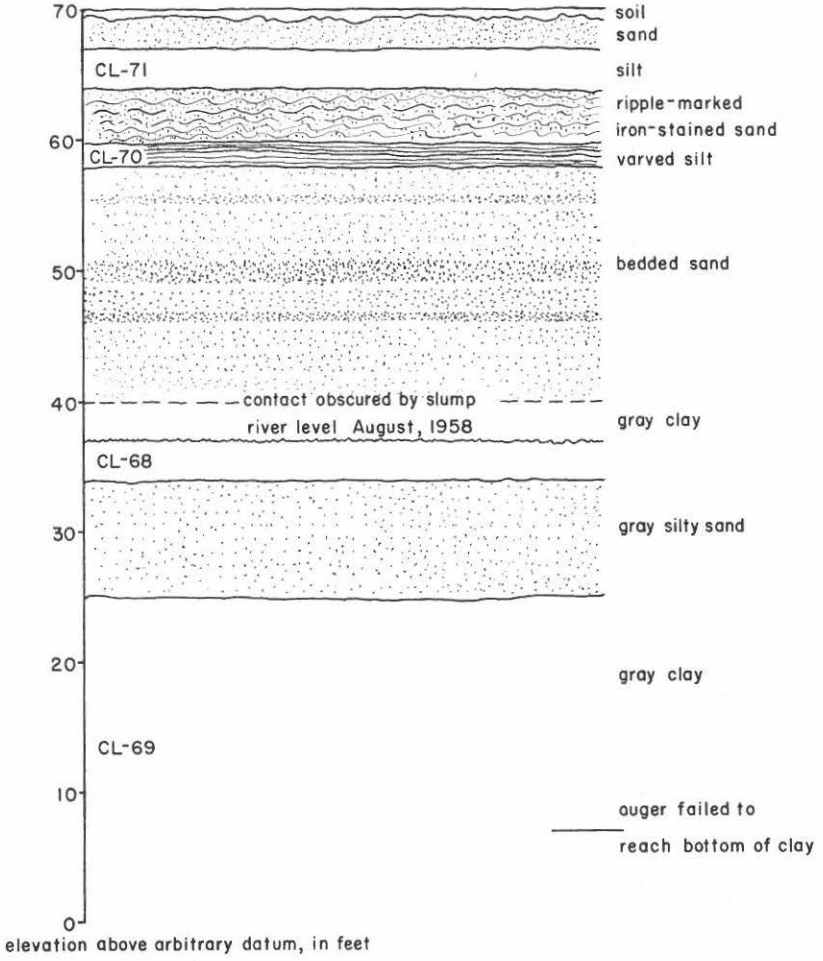

FIGURE 2. Stratigraphic section exposed on west bank of Sandy River, about 1 mile east of Farmington Falls, Maine (locality 70, Plate 1). The stratigraphy below river level was determined by auger drilling.

At locality 70 (Plate 1), about 1 mile east of Farmington Falls, on the south bank of the Sandy River, the section shown in Figure 2 is exposed. A thin layer of clay was exposed at river level at the time of sampling. A 30-foot auger hole started at river level failed to reach the bottom of a deposit of clay which underlies the clay exposed at river level and a bed of silty sand between the two clay units (see Figure 2), and thus no estimate can be made of the thickness of this lower clay layer. The most significant part of this exposure is the interbedded deposit of silt and sand which overlies the clay. Although this exposure is better than others in the upper Sandy River valley, it is considered as being representative of the stratigraphy of the main Sandy River valley from Farmington Falls upstream to Farmington (see Plate 1).

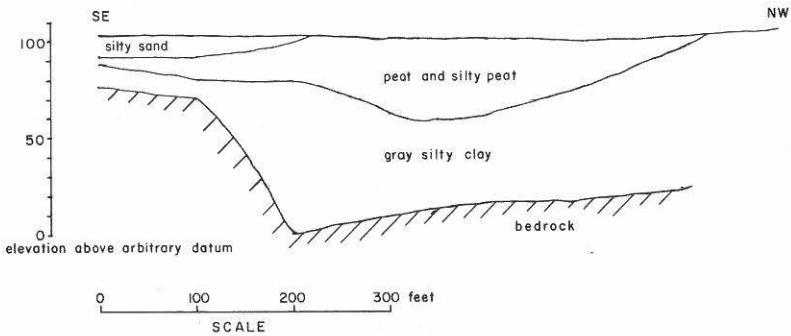

FIGURE 3. Stratigraphy of McGurdy Stream valley, north of Crowell Pond, New Sharon, Maine (see Plate 1), based on the logs of wash borings by Soils Laboratory, Maine Highway Commission. Line of section is along part of Route 41, which has settled greatly as a result of the compaction of the peat.

The logs of wash borings by the Soils Laboratory, Maine State Highway Commission at the north end of Crowell Pond, in New Sharon, were used to reconstruct the stratigraphy shown in Figure 3. The section in Figure 3 is a generalized version of a section in the Soils Laboratory report dealing with engineering problems at the site (Boyce, 1959). The stratigraphy revealed in this section is considered as being typical of the McGurdy Stream valley and the Little Norridgewock Stream valley in the vicinity of Chesterville (see Plate 1). The significance of the deposit of peat and peaty silt which overlies the clay at the Crowell Pond locality and which distinguishes the stratigraphy in this area from that in the main Sandy River valley will be discussed in a follow-

ing section dealing with the inferred geologic history of the Sandy River valley. Although greater thicknesses of clay likely occur locally in the Sandy River valley, the clay at the Crowell Pond locality has the greatest known thickness.

At locality 60 (Plate 1), near MacQuillis Corner, about 2 miles southeast of the village of East Wilton, a single auger hole revealed the following stratigraphy:

Peat	2 feet
Soupy brown sandy silt	2 feet
Brown to gray sandy silt	2 feet
Blue-gray clay	6 feet
Soupy gray clay	2 feet
Coarse gravel	not penetrated by auger

The location of this clay deposit is significant, because it indicates that clay deposition occurred locally in the upper Sandy River valley in areas at about the same elevation as the main valley, but far removed from it. It is generally characteristic of these backwater clay deposits that they are overlain by silt and sandy silt rather than the thick layers of coarse sand which overlie the clay in the main valley (see Figure 2).

The clay pit which provides the material used at the West Farmington brick yard affords a good exposure of the clay deposited in that area (locality 51, Plate 1). The stratigraphy exposed in the clay pit and that interpreted from the logs of an auger hole started at approximately the lowest point in the clay pit is as follows:

Fine to medium sand	1-3 feet	Exposed
Brown clay	20 feet	
Gray clay	6 feet	Auger logs
Medium sand	9 inches	
Interbedded gray clay and coarse sand	1½ feet	
Coarse sand	1 foot	
Interbedded gray clay and coarse sand	6 inches	
Mostly massive gray clay with local thin laminations	20 feet*	

*auger failed to reach bottom of clay

The stratigraphy at the West Farmington clay pit is thought to be typical of areas in the upper Sandy River valley which are closer to the main valley than such areas as locality 60 described above, but not actually in the main valley where greater thickness of sand usually overlie clay deposits.

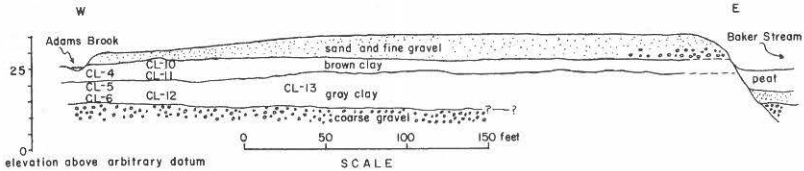

FIGURE 4. Stratigraphic section between Adams Brook and Baker Stream, Farmington, Maine, based on logs of hand auger. Erosion by Baker Stream has removed the clay which originally occurred at east end of section.

About 2 miles north of the village of Fairbanks, near the junction of Adams Brook and Baker Stream, a series of 5 auger holes were drilled in a line across portions of the floodplains of these streams. The stratigraphy inferred from the logs of these auger holes is shown in Figure 4. The most important part of this section is at the east side near Baker Stream, which indicates that the erosion of Baker Brook as it meandered and widened its floodplain, has removed any clay which was originally deposited. In the middle part of the section the clay has been preserved, for the stream has not occupied that part of the valley since the clay was deposited. At the west end of the section clay has been preserved because the smaller Adams Brook has not been able to erode deeply into the deposit of clay.

A relation similar to that described above is inferred to exist between the clay in the main Sandy River valley and the modern floodplain of the Sandy River. Beneath the silts and sands which comprise the modern floodplain sediments clay is known to exist locally, as at locality 49 (Plate 1) where clay underlies about 18 feet of floodplain sediments. Under most of the modern floodplain however, it is thought that much of the clay has been removed by the river as it has meandered over the floodplain, especially where the floodplain is narrow.

Terraces are developed along the margins of the floodplain in much of the upper Sandy River valley, the best developed of which is the highest terrace which ranges in elevation from about 360 feet near Farmington Falls to about 420 feet near Fairbanks (see Plate 1). This high terrace is interpreted as being the remnant of a deposit of sand which originally covered most of the upper Sandy River valley, and which has since been eroded greatly by the Sandy River as it established its present floodplain.

Several terrace levels between the high terrace and the present floodplain probably represent stages in the slow downcutting of the Sandy River to its present floodplain. The effect of this sequence of events is that under the high terrace the clay has not been greatly eroded, but is merely covered with a variable thickness of sand, whereas under the lower terraces, which represent successive floodplain levels in the slow downcutting of the river, at least some clay (and in some places all of the clay) has been eroded, as it has under the present floodplain. This relationship is illustrated in Figure 5, which is a generalized section showing the high terrace, one lower terrace, the present floodplain, and the presumed distribution of clay under each feature. It should be emphasized that the actual stratigraphy in the field is likely much more complicated than the simplified relations described above and shown in Figure 5.

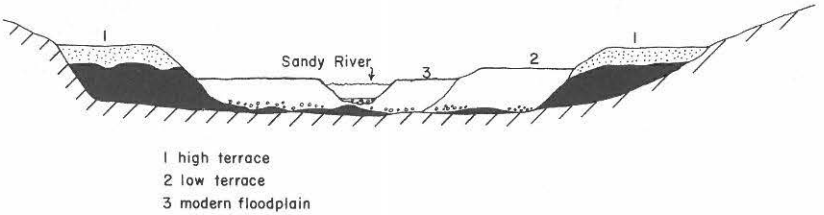

FIGURE 5. Generalized section of Sandy River valley, showing high terrace composed of outwash (stippled area), lower terrace and modern floodplain composed of alluvial silt, sand, and gravel, and their relation to the clay deposits (solid area). Width of section about one mile.

Following a discussion of clay deposits in the lower Sandy River valley, the history inferred from the stratigraphy in both the upper and the lower valley will be discussed.

CLAY DEPOSITS IN THE LOWER SANDY RIVER VALLEY — As mentioned before, the clay in the lower Sandy River valley is in many places exposed at the surface and bank exposures reveal enough of the stratigraphy to make it unnecessary to obtain further information by auger drilling. In general, the clay in the upper part of the lower Sandy River valley has little or no sand cover, but downstream sand deposits overlying the clay become thicker and more continuous.

Downstream from the village of New Sharon the Sandy River has eroded a deep, narrow gorge in glacial sediments (locality

73, Plate 1). This gorge affords a nearly continuous exposure of the stratigraphy for over 1 mile. The stratigraphy exposed on the south and southeast bank is shown in Figure 6. The significance of the glacial sediments will be discussed in the following section dealing with the glacial history of the Sandy River valley. For the purposes of the present discussion it may be said that the clay exposed at the top of the section is younger than the underlying glacial sediments and the upper surface of the clay, which apparently is the original surface of deposition, has not been eroded nor do any younger sediments cover the clay. The elevation of the upper surface of the clay at this locality is about 340 feet above sea level.

About 1 mile west of the town of Norridgewock, in the valley of the Kennebec River, a large gravel pit has exposed an interesting and significant section of sediments (locality 83, Plate 1). The source of the gravel in this pit is a large esker, the crest of which has been removed. The flanks of the esker which remain are mantled with a thin layer, from 3 to 10 feet thick, of brown and gray clay. Because the crest of the esker has been removed, it is not known if the clay originally covered the esker completely. About one half mile to the south the crest of the esker is lower and is completely mantled with about 20 feet of interbedded sand, silt and clay. The clay at locality 83 is overlain by gravel and sand which is interpreted as slope wash from the esker where it was not mantled by clay.

The gray clay is highly fossiliferous locally. *Yoldia Arctica* and several other marine pelecypods which occur in similar clay deposits in the Kennebec River valley, the Penobscot River valley, and in coastal areas of Maine are present at the Norridgewock locality. As far as the writer knows, the Norridgewock locality is farther inland and higher in elevation (280 feet) than previously described fossil localities in Pleistocene clay deposits in the Kennebec River valley.

Origin of clay deposits in the Sandy River valley and their relation to glaciation

The stratigraphic evidence discussed above suggests to the writer that the clay deposits in the Sandy River valley consist of two distinct deposits; marine clay in the lower Sandy River val-

ley, downstream from New Sharon (Plate 1) and lake clay in the upper Sandy River valley.

MARINE CLAY – The occurrence of marine clay at about 300 feet above the present sea level and nearly 70 miles from the present coast is an indirect effect of the last Pleistocene glacier active in this part of Maine. At its maximum extent, the last glacier to cover central and southern Maine was probably more than 4,500 feet thick, because there is evidence that most of the higher mountains in Maine were completely covered by glacial ice. Glacial erratics located near the summit of Mt. Katahdin (elevation 5,267 feet) suggest the glacier which covered that mountain was at least 4,700 feet thick (Tarr, 1900; Antevs, 1932; Flint, 1957).

The crust of the earth does not have sufficient strength to support such a load, but must yield under the stress produced by the mass of ice. Part of the deformation of the crust is elastic and is recovered as quickly as the stress is removed, as the dimple produced by pressing one's finger on the surface of a rubber ball disappears when the finger is removed (Daly, 1934, p. 119). The crust of the earth was bulged downward by the weight of such glaciers as covered Maine during the Pleistocene, the greater the thickness of the ice, the greater the amount of downward bulging. But because the Pleistocene glaciers represented loads on the crust which lasted for long periods of time, the crust could not support these loads by simple elastic deformation. Gradually the rock beneath the crust was deformed plastically in response to the elastically basined crust (Daly, 1934, p. 119).

Melting of the Pleistocene glacier removed the load on the crust which then recovered from the deformation produced by the glacier. That deformation which was purely elastic recovered quickly, but the plastic response took place much more slowly, and indeed is still going on. With respect to the present sea level then, Maine was relatively lower immediately following the melting of the last glacier, which allowed the sea to invade much of southern and central Maine. During this marine submergence, clay was deposited on what was then the sea floor. As plastic recovery from the depression of the crust continued, however, the sea retreated from the previously inundated areas, and clay and other sediments deposited during the submergence were raised high above the retreating sea level. In general, marine

sediments formed during this post-glacial submergence are but a few feet above the present sea level near the coast and become higher with increasing distance inland from the coast. Thus clays thought to be marine from the nature of their contained fossils lie at approximately 25 feet above sea level near the coast, at about 100 feet near Augusta, between 280 and 340 feet in the Sandy River valley, and may reach elevations in excess of 400 feet farther upstream in the Kennebec River valley.

The lack of well defined shore features, such as beaches and wave-cut platforms, associated with deposits of marine clay suggests the submergence lasted but a short time. Evidently, almost as the sea reached its point of maximum submergence, it began to retreat because the land was uplifted. In the Gray, Maine area, there is evidence that the sea caught up with the retreating glacier and for some time actually lapped against it. Deltas formed by outwash in places cover deposits of marine clay. However, by the time further melting of the ice occurred in the Gray area, the sea had begun its retreat and was not able to submerge areas exposed by further melting northwest of Gray (Arthur L. Bloom, oral communication).

There is no direct evidence by which it is possible to relate the marine submergence in the Kennebec River valley and the position of the melting glacier. The marine clay which covers part of the esker at Norridgewock is clear evidence that marine submergence followed deglaciation in that area. The clay which covers the youngest glacial sediments in the New Sharon gorge is also considered to be of marine origin and was deposited during the post-glacial marine submergence.

Several workers have concluded that the stratified sand and gravel overlying clay deposits suggests presence of glacier ice. Arthur L. Bloom has found evidence in southwestern Maine that the glacier in that area advanced a short distance over marine clay (oral communication). The clay itself is evidence of the presence of a mass of glacial ice, because the clay represents the finer fractions of the suspended material in meltwater from a glacier. Evidently the marine clay deposits are time transgressive, being somewhat older in coastal areas than in the interior, and represent a wave of sedimentation which closely followed the retreating edge of the glacier. At times the sea caught up with the ice as it did in the Gray area, whereas at other times the shore

of the advancing sea was far removed from the ice. There are too many variables involved in deglaciation and marine submergence for any generalized statement of the relation between the two to be made.

Age of marine clays – The age of the submergence of the upper Kennebec valley is known from carbon-14 dating of pelecypod shells collected by Robert L. Dow of the Maine Department of Sea and Shore Fisheries, from marine clay near Clinton, Maine. These shells are 11,800 ± 240 years old. The marine clays in the lower Sandy River valley are probably about the same age.

Depth of water during marine submergence – Estimates of the depth of water during marine submergence have been reduced greatly in recent years. The previously mentioned lack of beach and wave cut features makes it difficult to determine the position of the shore in any area. The upper surface of clay in a particular area approximates the position of the sea floor during deposition, but differential compaction and post-depositional erosion of the clay make it impossible to establish the level of the sea floor over a wide area.

Leavitt and Perkins (1935) and others have concluded that deep, still water is required for the settling of the fine clay and silt size particles in the marine clay deposits. Leavitt and Perkins (1935, p. 119) present evidence which suggests the water was about 150 feet deep in the Waterville, Maine, area during the deposition of marine clay. Goldthwait (1949, p. 64-65) feels that shallow water, similar to that found on the tidal flats along the present coast of Maine where clay and silt is now being deposited, better explains the distribution of Maine clay principally in the lower portions of valleys.

LAKE CLAY IN UPPER SANDY RIVER VALLEY – No way has been discovered by which it is possible to distinguish all glacial marine clay from all glacial lake clay by a study of the clay itself. Ideally, lake clays are rhythmically banded, whereas marine clays are massive (Flint, 1957). Goldthwait (1953), however, mentions varved clays near Biddeford, Maine which contain marine fossils and the writer has found clays, which from other considerations he judged to be lake clays, which contain no visible bedding structures. Joint surfaces in weathered zones of marine clay are often coated with a purplish stain of manganese oxide (Leavitt and Perkins, 1935) but not only are such stains absent

from many deposits of undoubted marine clay, such stains also occur in clay deposits of fresh water origin. Grain size and chemical analyses can not distinguish between the two types of clays. Because occurrences of fossils are rare in deposits of marine clay and, from the writer's experience, are completely lacking in deposits of lake clay in Maine, it is not practical to base the distinction between marine clay and lake clay on fossil evidence.

The stratigraphy, described above, of the clay in the upper Sandy River valley is so uniformly different from that in the lower valley that it suggests to the writer that deposition of clay and associated sediments in the upper valley was under an entirely different control from the marine conditions in the lower valley. This evidence suggests a glacial lake existed in the upper Sandy River valley, the approximate boundary of which is shown in Plate 2. Glacial Lake Farmington is an appropriate name for this lake as most of the lake was in what is now the town of Farmington.

Origin of Glacial Lake Farmington – The prominent esker and associated stratified drift deposits in Chesterville (Plate 2) were formed by meltwater streams produced by the melting of a large stagnant block of ice in the lowlands north and south of Chesterville (Caldwell, 1953). The location of the esker clearly indicates that drainage during this final episode of glaciation flowed southward through the Chesterville valley to the Androscoggin River, and not northeastward through the New Sharon gorge as it does at present. Till deposits in the New Sharon gorge prevented drainage in that direction during the deposition of the stratified drift in the Chesterville valley and later also formed the principal dam which produced Glacial Lake Farmington.

With continued melting of the remnants of glacier ice, much of the upper Sandy River valley became ice free. Meltwater from ice which remained in the extreme headwaters was dammed by stratified drift in the south end of the Chesterville valley and by the till dam at New Sharon, and Glacial Lake Farmington was formed.

The level of Glacial Lake Farmington was controlled at any particular time by the lowest possible outlet. Various possible outlets exist, but it is not possible to determine which was being used at a particular time from the evidence presently available.

Several of these outlets and their present elevations are shown on Plate 2.

Clay deposition in Glacial Lake Farmington – The source of the clay deposited in Glacial Lake Farmington is similar to that of the marine clay in the lower Sandy River valley, viz., the rock flour carried into the lake by meltwater from the melting glacier. The thickness of clay which accumulated apparently was controlled more by the depth of the basin available than closeness to the source of the clay. Thus the thickest deposit of clay known in the upper Sandy River valley is the nearly 80 foot section at Crowell Pond (see Figure 3). However, there may exist greater thicknesses elsewhere in the upper valley.

The total thickness of sediments at the Crowell Pond locality is about 100 feet (Boyce, 1959), which certainly represents the minimum depth of water at the beginning of sedimentation in Glacial Lake Farmington in that area. The elevation of drainage channels near New Sharon (see Plate 2) suggests the lake may have been deeper by 75 feet. It is felt that this depth represents an extreme for Glacial Lake Farmington which was likely much more shallow over most of its extent.

History of Glacial Lake Farmington following Clay Deposition – The extensive and thick deposit of gravel, sand, and silt which covers the clays in the upper Sandy River Valley has been interpreted by Stone (1899), Leavitt and Perkins (1935), and Caldwell (1953) as having been deposited during the retreat of the sea from this area. Antevs (1935) implies the level of the 400 foot terrace near Farmington represents the maximum level of submergence by the sea of the Sandy River valley. Goldthwait (1949, p. 64) states that the maximum elevation of marine clay in Maine is about 440 feet, "in the Farmington district," but his map of marine clays in Maine shows their limit in the Sandy River valley to be somewhere near New Sharon. More recently, the sand deposits in the upper Sandy River valley have been mapped as outwash (Flint, et al, 1959), a view to which the writer subscribes, except that he feels that the outwash was deposited in standing water, i.e., Glacial Lake Farmington.

Were the sand plain of the upper Sandy River valley formed as a shoal deposit as the sea retreated from the area, it should continue through the New Sharon gorge to the lower Sandy River valley. It does not continue through the gorge because the gorge formed after the sand plain was deposited.

Well preserved deltaic structures and oscillation ripple marks (see Figure 2) in the sand and silt deposits covering the clay are evidence the sand plain was deposited in standing water, that is, in Glacial Lake Farmington before a deep drainage channel drained the lake through New Sharon gorge. In general, the sediments of the sand plain become finer when traced from north to south and are finer in backwater areas, such as described above at locality 60, than near the main part of the lake.

The source of the sediments which form this sand plain is problematical, although it is somehow related to glacial ice which persisted in the headwaters of the Sandy River. The usual interpretation of coarse sediments overlying glacial marine clays in Maine is that these sediments indicate a minor readvance of ice (Leavitt and Perkins, 1935). The writer feels that more rapid, perhaps almost catastrophic, melting of remnants of glaciers would result in the same sequence of sediments.

The sands plain apparently ends in the vicinity of North Chesterville in the Wilson Stream valley and near Crowell Pond in the McGurdy Stream valley (see Plate 1). South of these areas the lake clays are covered with peat and peaty silt, as described at Crowell Pond (see Figure 3). The cessation of sand deposition in Glacial Lake Farmington was apparently the result of the drainage of the lake through the New Sharon gorge, which established the Sandy River in its present course. Indirectly, the drainage of Glacial Lake Farmington may have been the result of the withdrawal of the sea from the lower Sandy River valley. Prior to this withdrawal, sea level may have been approximately the same as the level of Glacial Lake Farmington and streams draining the lake did not have the necessary energy to erode the channel. Withdrawal of the sea lowered the base level, causing the outlet stream to cut the gorge at New Sharon. If this interpretation of the history of Glacial Lake Farmington is correct, then the marine submergence in the lower valley was more or less contemporaneous with the existence of the lake in the upper valley.

With the establishment of the Sandy River drainage through the New Sharon gorge, streams in valleys south of Crowell Pond and Chesterville (see Plate 1) became tributary to the Sandy River. The southern limit of the sand plain in the Sandy River Valley, however, produced an effective dam. A later, smaller

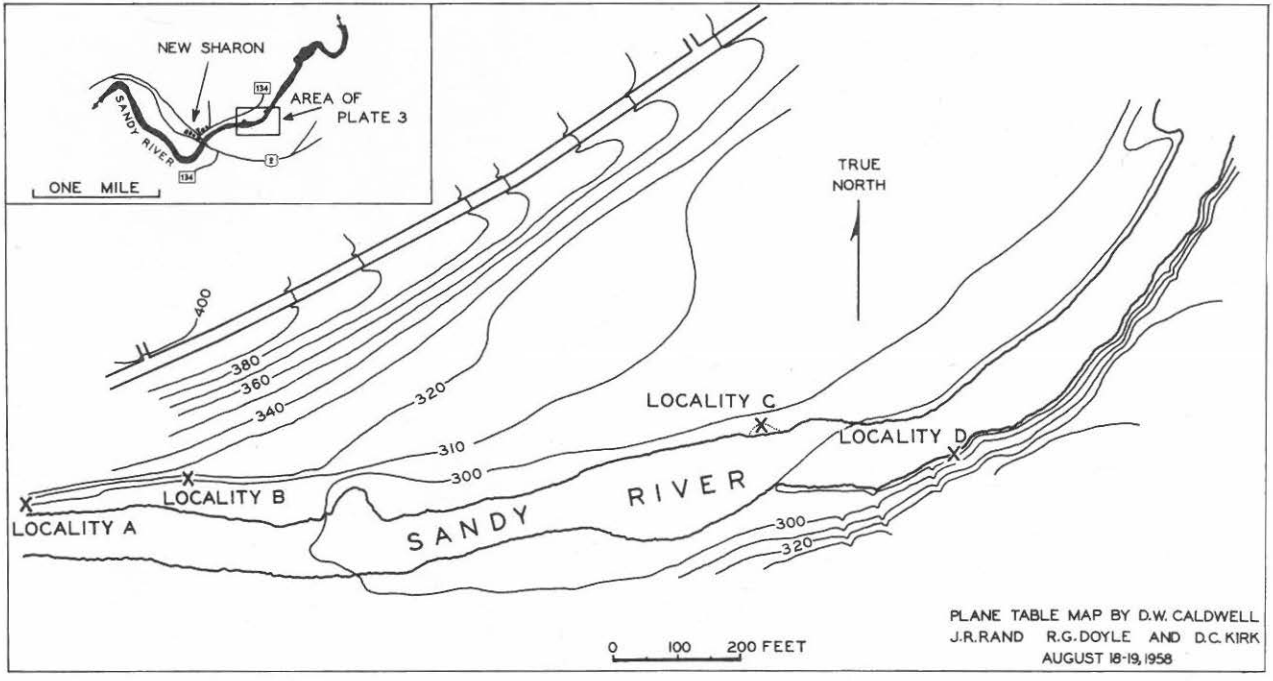

PLATE 3. Map of buried wood locality, New Sharon, Maine.

lake formed in these valleys following the draining of Glacial Lake Farmington. The extensive peat and silty peat deposits which form the swampy lowland in the Chesterville area accumulated in this lake; and locally, peat is still accumulating.

In the upper Sandy River valley after the draining of Glacial Lake Farmington, the valley floor was covered with extensive sand deposits. Locally, before the establishment of a vegetation cover, much of this sand was thrown into dunes, some of which evidently migrated for short distances. The long ridge of sand on the north flank of Cape Cod Hill in New Sharon is thought to have originated in this manner. Other sand dunes, now stabilized, occur in the town of Fairbanks between the Sandy River and Baker Stream. North of Farmington Falls is an area of dune sand which is now active because the soil cover was destroyed as a result of overgrazing. Several of these dune sand deposits are shown on Plate 2.

SUMMARY OF THE GLACIAL GEOLOGY OF THE SANDY RIVER AREA – The glacial sediments exposed in the New Sharon Gorge record two distinct phases of late Pleistocene glaciation. At localities A and B (Plate 3) deformed varved clay is overlain by blue-gray till. At locality C (Plate 3) the following section is exposed near the river level:

Boulder pavement	2 to 4 feet
Blue-gray till	2 feet
Gray varved clay with scattered pebbles	1 to 6 inches
Brown, sandy silt containing fragments of wood, cones, twigs	6 to 40 inches
Greenish gray sandy silt upper surface oxidized 6-12 inches; locally oxidized zone missing	10 to 30 inches
Greenish gray till	1+ feet

Fragments of wood collected for carbon-14 dating from the brown sandy silt were submitted to the Yale University Geochronometric Laboratory. The stratigraphy exposed at localities D and E (Plate 3) is presented in Figure 6 and may be summarized as follows:

Locality D.

Soil	2 feet
Brown silt	4 feet
Gravel	2 feet
Blue-gray till with interbedded varved clay	20 to 25 feet
Varved clay	1 inch to 3 feet
Gray boulder-clay with carbonate concretions	2 to 10 feet

Locality E.

Brown marine clay	2 to 16 feet
Gray sandy till	15 to 25 feet
Gray gravelly sand	6 to 8 feet
Coarse sand with interbedded silt: bedding structures highly deformed	2 to 18 feet
Brown sandy silt	4 to 12 feet
Brown clay-rich till	1 to 3 feet
Brown to gray silt	2 to 4 feet
Coarse sand	1 to 2 feet

The upper till exposed at each locality described above is similar to the till which occurs in much of the Sandy River area and is thought to be a deposit of the last glacier active in this region. It is suggested that this episode of glaciation be named the Sandy River substage. The stratified drift deposits in the Chesterville area record the melting of this glacier. The clay and outwash in both the upper and lower Sandy River valley were deposited following the melting of the same glacier.

An older stage of glaciation is represented in the New Sharon area by the till which underlies blue-gray Sandy River till at locality C. A deglaciation having at least local significance may be inferred from the organic silt which occurs between the two tills exposed at locality C. The name, New Sharon substage, will

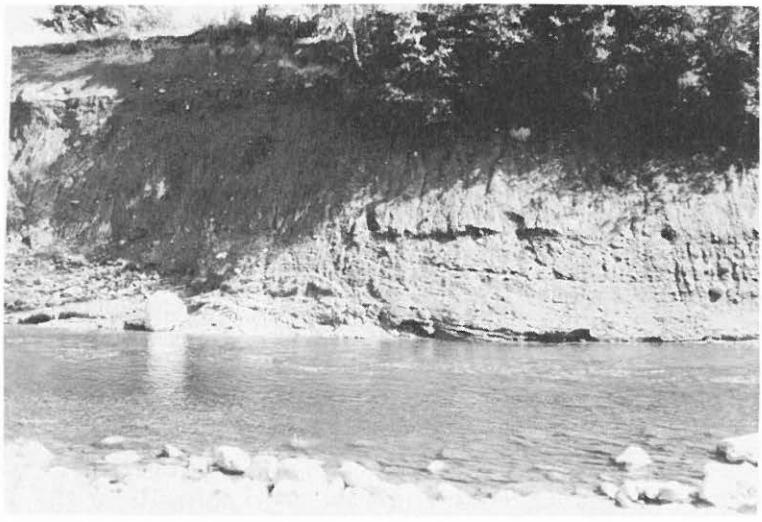

FIGURE 7. Photograph of sediments exposed at locality D, Figure 6 and Plate 3. Large boulder at water level rests on platform of New Sharon till. Anticlinal structure to right of boulder is contact between upper Sandy River till and lower New Sharon till. Varved clay layers at base of Sandy River till are visible at water level at right of anticlinal structure.

be used to describe the older episode of glaciation recorded in the New Sharon gorge. The boulder-clay at locality D and the deformed sand, silt, and till at locality E are tentatively correlated with the New Sharon substage.

Two interesting features of the stratigraphy at the New Sharon site deserve further mention. At both locality C and locality D, a thin layer of varved clay occurs at the base of the upper Sandy River till, and other varved clay layers are interbedded in the till at locality D (Figure 7). Evidently the Sandy River glacier advanced into a lake in which the basal varved clay was deposited. The varved clay interbedded in the Sandy River till was formed during minor oscillations of the margin of the Sandy River glacier. On the bedding plane surfaces of the varved clay layers well preserved lineations record the direction of movement of the overriding glacier (Figure 8).

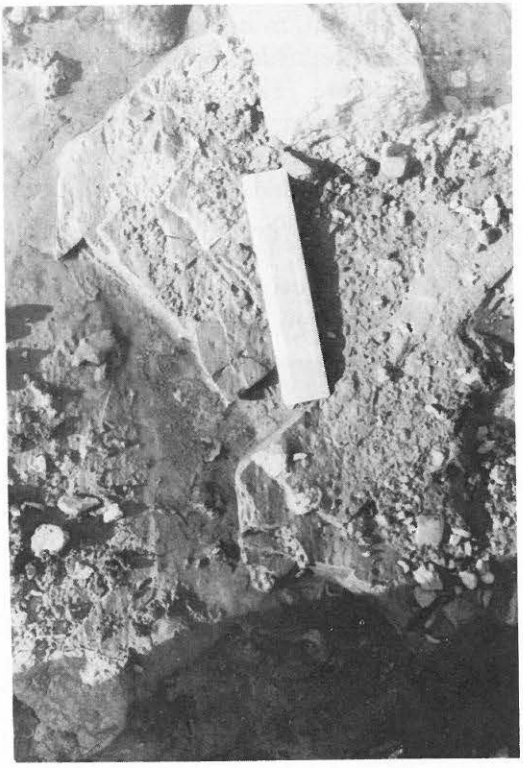

FIGURE 8. Photograph of varved clay at base of Sandy River till, locality C, Plate 3. Lineations on bedding plane are approximately parallel with striations in the area and were evidently formed by overriding ice. Note regular joint sets.

At locality D (Figure 6 and Figure 7), carbonate concretions occur in sediments related to the New Sharon substage of glaciation. These concretions were formed by the solution and redeposition of calcium carbonate from fragments of limestone in the New Sharon substage sediments. Some concretions occur in layers of silt and clay in the

position in which they formed (Figure 9), whereas other concretions were incorporated in the till of the New Sharon glacier and now occur randomly in that till. No concretions were found in the upper Sandy River till.

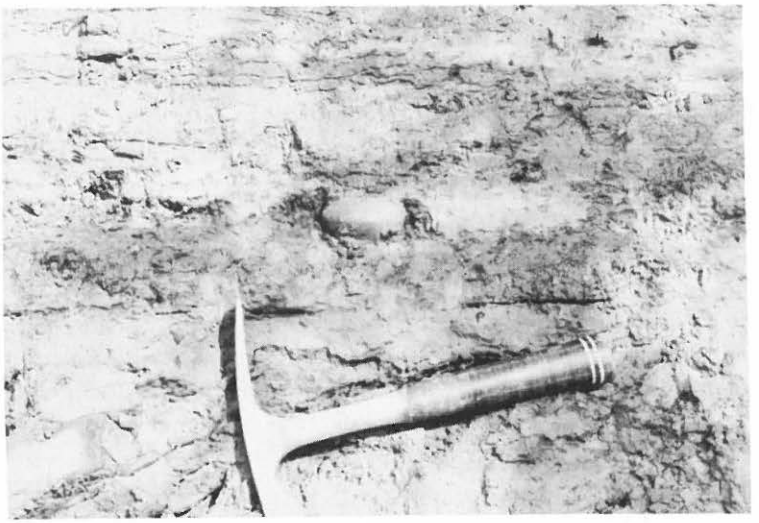

FIGURE 9. Photograph of carbonate concretion in brown sandy silt.

The concretion-bearing silt and clay layers and the presence of similar concretions in the New Sharon till suggest that the New Sharon glacier, like the Sandy River glacier, advanced into a body of standing water, and that clay was deposited over the New Sharon till following deglaciation, as happened following the melting of the Sandy River glacier.

The lack of other two-till exposures in the Sandy River area makes it impossible to determine the regional significance of the New Sharon sequence at this time. Although it is certain that both the Sandy River and the New Sharon substages are part of the Wisconsin or youngest Pleistocene stage of glaciation, no correlation with the standard mid-west sequence can be made. Flint (1953) presents evidence which indicates the last Wisconsin glaciation in southern Maine may be correlated with the Cary substage in the mid-west, but later states that the terms Iowan, Tazewell, Cary, and Mankato should not be used to describe Wisconsin substages except in the mid-west (Flint, 1957).

TABLE 1. Correlation of Late Wisconsin events in the Sandy River area, Maine.

	UPPER SANDY RIVER VALLEY	NEW SHARON GORGE	LOWER SANDY RIVER VALLEY
	Channel cutting — establishment of present flood plain	Channel cutting — establishment of present flood plain	Channel cutting — establishment of present flood plain
Glacial Lake Farmington Marine Submergence	Formation of sand dunes. Peat deposition in Chesterville area. Draining of Glacial Lake Farmington through New Sharon Gorge.	Uplift: retreat of sea	Uplift: retreat of sea
	Deposition of sand over clay: accelerated melting?		Deposition of sand over clay
	Clay deposition in Glacial Lake Farmington	Deposition of marine clay	Deposition of marine clay (11,800 years before present)
	Deglaciation: formation of stratified drift followed by beginning of Glacial Lake Farmington	Deglaciation: marine submergence	Deglaciation: formation of Norridgewock esker followed by marine submergence
Sandy River substage	Deposition of Blue-gray till	Deposition of blue-gray till: interbedded varved clay suggests minor oscillations of margin of glacier	
		Formation of soil	
New Sharon substage		Deposition of lower till	

The sequence of events during the late Wisconsin stage which are inferred from the stratigraphy of the Sandy River area is presented in Table 1. Further field work in this area should serve to establish the regional significance of the two substages of Wisconsin glaciation recorded here.

Physical, chemical, and thermal expansion properties of clay

The procedures and results of several laboratory tests and analyses performed on the clays collected in the Sandy River area are described in the following sections of this paper. Also described are the results of the same tests performed on clay samples from the Portland-Gray area, Brewer, and Sidney. These tests included size analysis and expansion by rapid firing at high temperatures of nearly all samples collected, determination of plastic properties of about one fourth of the samples, chemical analysis of 5 samples, and strength tests of 4 concrete samples using expanded clay as a lightweight aggregate.

SIZE ANALYSIS – Procedure. The distribution of the particle sizes in the clay samples was determined by pipette analysis, following the procedure outlined by Krumbein and Pettijohn (1938). For each sample, cumulative frequency curves of the size distribution were prepared, using semilogarithmic graph paper. An example of this type of plot is shown in Figure 10.

The median diameter (the diameter which is larger than 50% of the particles and smaller than the other 50%) is read directly from the cumulative curve (Figure 10). The degree of sorting or spread of sizes on either side of the median diameter as expressed by the coefficient of sorting defined by Trask (1932), is also determined from the cumulative frequency curve. The modal diameter (the most frequently occurring diameter in the distribution) and the percentage of particles of clay size in each sample were determined directly from the frequency data.

Results of size analysis. The median diameter, the Trask sorting coefficient, the modal diameter, and the percentage of clay sized material in each sample for which these determinations were made are listed in Appendix 1.

These data show that 16 samples, or about 28% of the samples for which particle size was determined, have median diameters

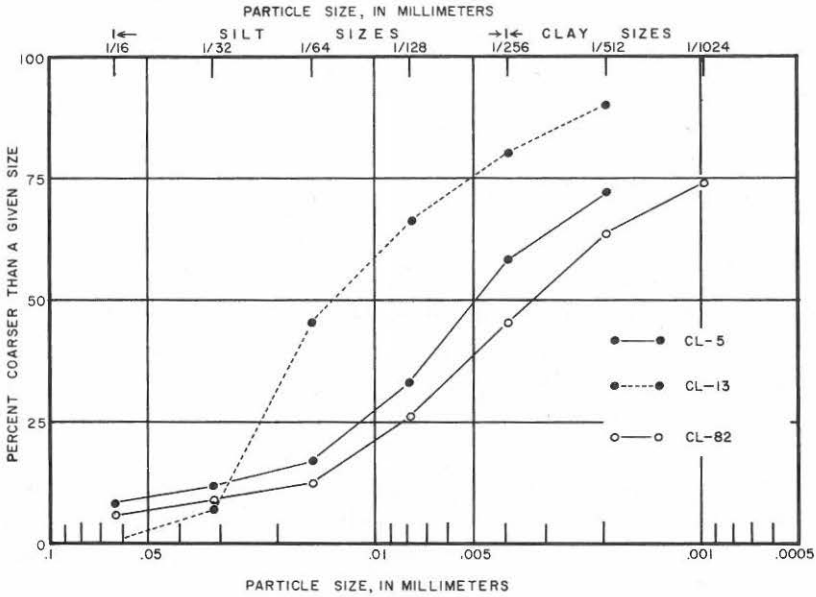

FIGURE 10. Cumulative frequency curves of particle size distributions of selected clay samples from the Sandy River area, Maine. Median diameter and coefficient of sorting are determined from the frequency curves. For example, sample CL-5 has median diameter of .005 mm.

in the clay sizes (finer than 1/256 mm or .0039 mm). The median diameters of all other samples are in the silt size range, suggesting that the majority of samples considered in this paper are strictly speaking silts rather than clays. It is interesting to note that in about one half the cases for which information was gathered, the particle size (median diameter) decreases with increasing depth in the stratigraphic column, but in the other half the upper sediments are finer than the lower or deeper sediments.

The modal diameter is the size which occurs most frequently in a particular sediment, and for this reason is in some respects the most characteristic measure of the "average" size of a sediment (Krumbein and Pettijohn, 1938, p. 243). The modal diameters of all but 5 of the samples considered in this paper are in the silt size range (see Appendix 1), which is further indication

that the sediments collected in the Sandy River area are for the most part silts rather than clays. The data in Appendix 1 show that in nearly all samples the modal diameter is larger than the median diameter.

According to Goldthwait (1953) Maine clays contain on the average about 39% of clay-size particles. This observation agrees well with data relating to the percentage of clay-size particles in the Sandy River clays (see Appendix 1), which show the average clay-size content to be about 40%. The range of percentages of clay-size material is from 12% to 67%.

The Trask sorting coefficient is a measure of the range of conditions during transportation and deposition of sediments (Krumbein and Sloss, 1951, p. 75). Values of S_O of clays sampled in the Sandy River area range from 1.9 to 6.0. For many samples, the higher values of S_O (poorer sorted) are associated with finer particle sizes and the best sorted sediments are coarse silts. There is neither a regular increase nor decrease in degree of sorting with the depth from which samples were collected. The poorest sorted sediments are varied clays which contain ice-rafted coarse material. The majority of the sediments have values of S_O between 2.5 and 4.0, which represents a moderate degree of sorting according to Trask (1932).

The various size characteristics described above do not distinguish between lake clays and marine clays, nor are there any consistent differences between the size characteristics of the upper brown clays and those of the lower gray and blue-gray clays. However, in following sections of this paper it will be shown that particle size apparently influences both the chemical composition and the thermal expansion characteristics of the clays sampled in the Sandy River area.

INDEX OF PLASTICITY – It has been shown above that the majority of sediments discussed in this paper do not have the size characteristics of clay sediments. In a following section it will be shown that the chemical and inferred mineral compositions of these materials are not those of true clays. However, with the proper water content, nearly all of the sediments which are discussed in this paper have the property of plasticity commonly associated with clay sediments. Practically speaking then, these sediments may be considered as clays.

The methods used in the determination of the plasticity index of the Sandy River clays are described by Terzaghi and Peck (1948, p. 32-33). Essentially this involves the determination of the plastic limit, P_L, or the lowest water content at which the material is plastic; and the liquid limit, L_L, or the highest water content at which the material is plastic. The index of plasticity, P_I, is the numerical difference between the liquid limit and the plastic limit. These data are shown in Appendix 1.

The indices of plasticity of the Sandy River clays range from a minimum of about 9% to a maximum of about 33%. This range is similar to the range of indices of plasticity of glacial-lake sediments in Alaska (Wahrhaftig and Black, 1958, p. 85), but much greater than that of lake clays in New Hampshire studied by Chapman (1950). The indices of plasticity of Chapman's clays range from about 27% to 31%.

COLOR – The colors of clays in the Sandy River area are classed as either brown or gray, no attempt being made to distinguish between the various shades of gray which, in the opinion of the writer, are more the result of differences in water content than of differences in particle size or composition.

Most workers agree that the upper brown clay which commonly overlies gray or blue-gray clay in Maine and New Hampshire represents the oxidized lower clay (Trefethen, J. M., 1947; Goldthwait, L. G., 1949, 1951, 1953; Zink, R. M., 1953) and not a separate sedimentary unit.

As mentioned before, there is no significant difference in the particle size characteristics of brown and gray clay samples from the Sandy River area. However, chemical analyses of two pairs of clays, one pair of which is marine clay and the other glacial-lake clay, each pair consisting of a brown clay and a gray clay which in the field were sampled from the same exposure or auger hole, suggest a significant chemical difference between brown and gray clay (see Table 2). In each pair, the brown clay contains a higher percentage of ferric iron and a lower percentage of ferrous iron than the underlying gray clay. Expressed in terms of the ratio between Fe_2O_3 and FeO of brown clay and gray clay, the ferric iron: ferrous iron ratio of brown clay is from 2 to 2.5 times as great as that of gray clay. Such a change would be expected if the brown clays were the results of the weathering of the gray clays.

TABLE 2. Chemical analyses of selected clay samples from the Sandy River area, Maine.

Sample	CL-10	CL-12	CL-97	CL-98	CL-84	CL-84E
SiO_2 %	60.1	60.7	64.2	61.2	56.8	59.1
Al_2O_3	18.8	18.2	17.2	18.0	20.6	21.7
FeO(ous)	3.2	4.4	3.6	4.7	5.2	5.9
Fe_2O_3(ic)	4.1	2.3	2.2	1.4	2.5	2.0
CaO	1.6	2.0	1.4	2.1	1.4	1.2
MgO	2.7	2.8	2.6	3.1	3.3	3.5
Na_2O	1.5	1.8	1.7	1.6	1.5	1.3
K_2O	2.7	2.6	2.8	2.8	3.3	3.7
TiO_2	1.1	1.0	0.92	0.94	1.0	1.1
CO_2	under .1	under .1	under .1	under .1	under .1	under .1
Ignition Loss	3.9	3.1	3.2	3.7	4.2	nil

Analyses by Thompson & Lichtner Co., Inc. 8 Alton Place, Brookline 46, Massachusetts

CL-10 Brown glacial lake clay
CL-12 Gray glacial lake clay } Locality 10, Plate 1

CL-97 Brown marine clay
CL-98 Gray marine clay } Locality 83, Plate 1

CL-84 Gray marine clay

CL-84E Sample CL-84 after firing for 3 minutes at 2025°-2050°F.

CHEMICAL ANALYSIS OF SANDY RIVER CLAYS – Chemical analyses of 5 clay samples from the Sandy River area are shown in Table 2. Samples CL-10 and CL-12 are brown glacial-lake clay and gray glacial-lake clay respectively, sampled from the same auger hole (locality 10, Plate 1. See also Figure 4). Samples CL-97 and CL-98 are brown marine clay and gray marine clay, respectively, sampled from an exposure in a gravel pit near Norridgewock, Maine (locality 83, Plate 1). Also included in Table 2 are the analyses of a sample of marine clay and the same material after expansion at high temperature (samples CL-84 and CL-84E). The significance of these two analyses is discussed in the following section dealing with the expansion of the clays.

The chemical analyses of the fresh clay samples from the Sandy River are very similar to analyses of other glacial-lake and marine clays from New Hampshire (Chapman, 1950), Alaska (Wahrhaftig and Black, 1958), and Finland (Pettijohn, 1957). They are also similar to the analyses of argillites from Canada (Pettijohn, 1957, p. 345), phyllites from Norway (Rankama and Sa-

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... of lime in those samples, the data in Table 2 indicate the

from the Sandy River area, Maine.	CL-98	CL-84	CL-84E
	1.2	56.8	59.1
	20.6	21.7	
	5.2	5.9	
	2.5	2.0	
	1.4	1.2	
	3.3	3.5	
	1.5	1.3	
	3.3	3.7	
	1.0	1.1	
	.1	under .1	
Massachusetts		nil	

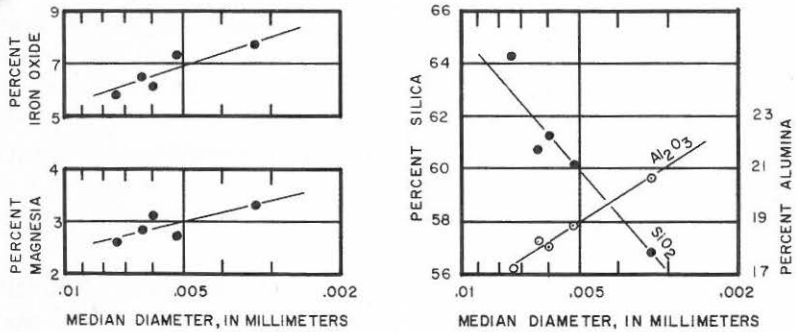


FIGURE 11. Relation of chemical composition and particle size, expressed as the median diameter, of selected clay samples. As particle size decreases, the amount of silica decreases and the amounts of alumina, iron oxide, and magnesia increase. Chemical analyses are shown in Table 2.

unfossiliferous clays, CL-10, CL-12, and CL-84 have about the same lime content as the fossiliferous clays.

The effect of the particle size on the chemical composition of the clays is well illustrated in Figure 11, which relates the percentage of various components to the particle size, as measured by the median diameter. As particle size decreases, the percentage of alumina increases and that of silica decreases, or in other words, the ratio of alumina to silica increases. Whereas no regular change in either ferric or ferrous oxide alone with particle size is noted, there is a fairly uniform increase in total iron oxide content with decreasing particle size. Also shown in Figure 11 is the slight increase in magnesia with decreasing particle size. According to Pettijohn (1957, p. 101 and p. 343) such changes characterize many clastic sediments and are the result of mineralogical changes which accompany changes in particle size. For example, the decrease in silica represents the fewer quartz grains in the finer sediments, whereas the increase in alumina, magnesia, and iron represents an increase in clay minerals and iron-rich magnesium-bearing chlorite in the finer sediments (Pettijohn, 1957, p. 343).

The inferred presence of clay minerals in the Sandy River clays does not necessarily imply that chemical weathering of the nearby bedrock produced residual clays which were subsequently eroded by the last glacier active in this area. Rather, the clay minerals and other minerals such as chlorite which characterize many shales, slates, and phyllites were probably derived directly from local bedrock sources and eventually were contributed to the muds on the sea and lake bottom without further change. Those clays (CL-97, Table 2) which have ratios of alumina to silica which are much lower than a phyllite or slate presumably contain a larger percentage of silt-size quartz particles than other clays. Thus both the chemical and mineral composition of the clays are closely related to their particle size, which in turn is related to the conditions during deposition of the clays.

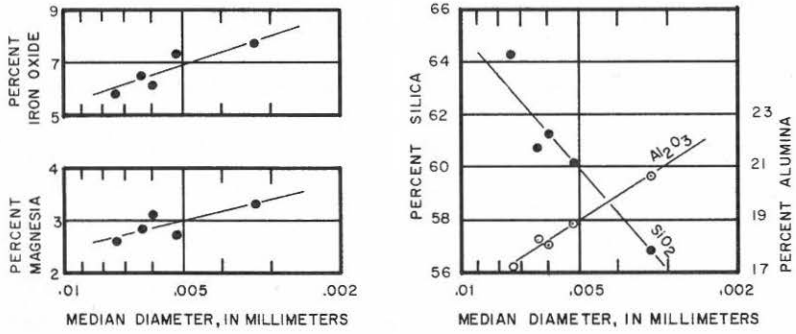
EXPANSION OF CLAY AND USE AS LIGHTWEIGHT AGGREGATE – Glacial lake and marine clays have not had extensive commercial use in Maine. At present there are about five brick yards in Maine which use clay as the principal raw material in the manufacture of bricks. Otherwise, except for such uses as pottery clay, a home remedy for bee stings and poison ivy, and

hama, 1950, p. 222), and a composite sample of 52 terrigenous muds (Rankama and Sahama, 1950, p. 222).

The bedrock north of the Sandy River area consists principally of slates and phyllites with some lime-silicate-gneiss and minor intrusive bodies of granite. The similarity between the chemical composition of the Sandy River clays and the composition of argillaceous sediments and rocks suggests the Sandy River clays represent the unaltered product of the glacial erosion of the nearby bedrock. Leavitt and Perkins (1935) and others have long considered these glacial clays to be a "rock flour," mechanically derived from bedrock and deposited from glacier meltwater streams in bodies of standing water, and not the result of chemical weathering.

Part of the variation in chemical composition of the Sandy River clays is the result of the post-depositional weathering of what is inferred to be the original gray clay, which produced the changes in the relative amounts of ferric and ferrous iron discussed above in the section dealing with the color of clays. Other changes produced by the weathering of the gray clay to brown clay are indicated by the fairly consistent decrease in soda, magnesia, and potash (see Table 2).

Although it was expected that the presence of mollusk shells in samples CL-97 and CL-98 would increase significantly the amount of lime in those samples, the data in Table 2 indicate the



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surfacing for tennis courts, most clay deposits in Maine are at best considered as nuisances. The results of tests performed on the Sandy River clays suggests, however, that Maine possesses an extensive and potentially valuable resource in these and other similar clay deposits as raw material in the production of lightweight aggregate for lightweight concrete.

Preparation of samples. Small pellets of clay were made by extruding plastic clay through an opening 1 cm in diameter. Long pencils of clay were thus produced and then cut to 1 cm lengths. For each clay sample between 50 and 100 pellets were prepared.

In the determination of the amount of expansion in each clay sample, the average volume of the expanded clay pellets is compared with the original volume of the unexpanded pellet. For this reason it is important to determine how much variation there is in the volume of the unexpanded pellets. If it is assumed that the weight of the unexpanded pellets varies only with volume, a comparison of the weights of a large number of pellets would give a measure of the variation in the volume of the pellets. About 250 pellets, representing 5 different clay samples were weighed. For each sample, the mean weight of about 50 pellets was determined. The extreme variation in weight from mean weight ranged from 12 per cent to 18 per cent of the mean weight, although in two groups of pellets, about 70 per cent of the pellets varied less than 5 per cent from mean weight. Thus no important error is introduced into the calculation of the amount of expansion in each clay sample, if the original volume of the clay pellets is considered to be uniform.

Each sample of 50 to 100 pellets was dried at approximately 110°C for 24 hours. This was done in order that each sample would have about the same soil moisture content when fired in the furnace. Unfortunately, several weeks elapsed between the drying and the firing of many of the clay pellets, during which some moisture probably was absorbed by the pellets from the atmosphere.

Procedure for expanding clay. The clay pellets were expanded by introducing them into a Hoskins type muffle furnace (K. H. Huppert Company type 11 BMIF furnace). Temperature of the furnace was recorded by a pyrometer and was manually controlled during firing.

From each group of 50 to 100 pellets, 10 to 15 pellets were selected at random and placed in the furnace which maintained a temperature of approximately 2000°F. The pellets remained in the furnace between 1 and 5 minutes, the actual firing time of each sample being recorded, together with the temperature, at the beginning and end of each firing. Experience showed that some clays exploded violently with such rapid heating, but this was avoided simply by pre-heating the pellets slightly on the top surface of the furnace.

The firing times and range of temperatures during the firing of the clay pellets are shown in Appendix 2. Experience showed that little further expansion occurred after more than 3 to 4 minutes of firing. Willard J. Sutton of the College of Ceramics, State University of New York, Alfred, New York, suggested that 15 minutes total firing time was required to obtain maximum expansion of clays (personal communication). This, however, involved firing in a rotary kiln, into which the clay pellets could be slowly introduced and gradually heated to the optimum temperature for expansion.

Temperature during firing is apparently a more critical control of the amount of expansion than is the firing time. Sample CL-19 was fired at several different temperatures and firing times which are recorded, together with the amount of expansion, in Appendix 2. These data show that there is a great deal of variation in the degree of expansion, depending on both the time and temperature of firing. Part of the variation in expansion, however, is probably caused by variations in composition of the clay, the degree of packing, the initial size of the clay pellets and certain uncontrollable factors in firing technique. For these reasons, the data concerning the expansion of sample CL-19 shown in Appendix 2 are not considered as significant.

Ten other samples were fired at two different temperature ranges; generally speaking, at about 1900°F and at about 2050°F. The data in Appendix 2 show clearly that at the lower temperature the amount of expansion is less than the amount of expansion at higher temperature, with the exception of sample CL-81 which achieved greater expansion when fired for a longer time at a lower temperature.

The results of expansion of Maine clays suggests the minimum temperature at which maximum expansion will occur is about

2000°F (1100°C), at least with the equipment and techniques which were used. Sutton (personal communication) suggests that temperatures between 1832°F (1000°C) and 2000°F (1100°C) promote good expansion of clay in a rotary kiln, although the material is fired for 15 minutes. A commercial rotary kiln in Denmark burns clay pellets at about 2050°F (1125°C) (Andreasen, 1950). Glacial clays studied by Chapman (1950) in New Hampshire were expanded at approximately the temperatures used in expanding the Maine clays, although Chapman describes the temperature in terms of pyrometric cone numbers (all samples described by Chapman expanded at cone 02), which is a measure of both firing temperature and time.

Amount of expansion. The amount of expansion of the clay pellets was determined by measuring the volume of water displaced by the submerged pellets. Both the maximum expansion of a single pellet and the average expansion of the 10 to 15 pellets which comprised the sample were measured. The volumes (average and maximum) of the expanded pellets were then compared with the volume of the unexpanded pellet and the amount of expansion, both average and maximum, was calculated (see Appendix 2).

The average volume changes after firing range from a loss in volume equal to 40 percent of the original volume to an increase in volume equal to 440 percent of the original volume. Nearly 60 percent of the samples tested increased in volume by at least 100 percent, 32 percent of the samples increased in volume by at least 200 percent, 15 percent of the samples increased in volume by at least 300 percent, and less than 2 percent of the samples increased in volume by 400 percent or more of the original volume. The median value of these volume changes is an increase of about 130 percent of the original volume.

Cause of expansion. The expansion of clays fired in the manner described above is due to the formation of gas which is unable to escape from the clay because the surface becomes fused to glass during firing (Chapman, 1950, p. 12). The gas forms hundreds of small bubbles within the clay pellet which are preserved when the fused pellet is removed from the furnace. The bubbles produce a very porous material which resembles volcanic scoria, and because the bubbles are not connected to each other, the material is practically impermeable. The fused glassy surface and

the honey-comb-like interior of the expanded pellet impart to the pellet a fairly high compressive strength.

There is a fair correlation between the amount of expansion and the particle size of the Sandy River clays. In general, the amount of expansion increases as particle size decreases, whether particle size is expressed as median diameter or modal diameter. It is also indicated that for clays of a given particle size, gray clay expands more than brown clay. The data relating the amount of expansion to the particle size, as expressed by the modal diameter, are shown in Table 3. Also shown in Table 3 is the relation between the amount of expansion and the percentage of clay-size particles in the samples of clay. For both relations, the amount of expansion shown with each grade of particle sizes represents the average expansion of all samples within the particular grade.

TABLE 3. Relation of amount of expansion and particle size of Sandy River clays. Numbers in parenthesis refer to number of samples of each type.

	Amount of Expansion, in per cent of original volume	
Mode (mm)	Brown clay	Gray clay
.044	——	—8 (3)
.022	69 (3)	140 (5)
.011	61 (5)	168 (12)
.0055	159 (2)	231 (19)
.0039	253 (3)	——
.00276	216 (1)	440 (1)
% of clay-size particles	Brown clay	Gray clay
10-20%	29 (2)	—8 (3)
20-30%	73 (2)	111 (5)
30-40%	56 (3)	203 (8)
40-50%	168 (4)	202 (9)
50-60%	213 (3)	250 (11)
60-70%	40 (1)	320 (1)

Thus the amount of expansion of the Sandy River clays varies with the particle size and the percentage of clay-size particles of the clay, and is also definitely related to the color of the clay. Obviously, neither the particle size nor the color of the clay can directly influence the amount of expansion. Indirectly, however, both particle size and color do influence the expansion characteristics of the clays because they apparently are related to the chemical and mineralogical composition as shown above.

The decrease in silica content and corresponding increase in alumina, iron oxide, and magnesia content with decreasing particle size of the clay samples shown in Figure 11 was interpreted as suggesting that the percentage of clay minerals and chlorite increases with decreasing particle size. Clay minerals and chlorite (and the ordinary micas, muscovite and biotite) contain water molecules which under ordinary conditions are firmly held in the

crystal structure of the minerals. As mentioned before, all clay samples were dried at 110°C (230°F) before firing. Soil moisture, both connate and meteoric, would be driven off during this drying operation, but the water of crystallization in the clay and micaceous minerals would be unaffected. At temperatures exceeding 1800°F the water of crystallization is driven from the crystal structure and is then able to expand to form water vapor. The formation of this gas evidently is responsible for the expansion of the clay as described above.

Other gases, such as carbon dioxide, may also be formed during the firing of the clays and become involved in the expansion process. Andreasen (1950, p. 113) feels that carbon dioxide, formed by the reaction of iron oxide and carbon, is responsible for the expansion of clays studied by him. The lack of recognizable organic material in the Sandy River clays, together with the extremely low carbon dioxide content indicated by the chemical analyses of the clays (Table 2) make it doubtful that carbon dioxide plays an important role in the expansion of the clays considered in this paper. In a commercial production of expanded clay, however, the addition of suitable material to the raw clay to produce carbon dioxide should be considered (Andreasen, 1950, p. 114).

Because the expanded clay pellets comprising each sample fired were not weighed before firing, it was not possible to determine the loss in weight of the clay during firing. The results of the expansion of carefully weighed pieces of slate from Monson, Maine, by John R. Rand and Robert G. Doyle of the Maine Geological Survey indicate the weight loss of that material during firing ranges from about 3 to 4 percent of the original weight (personal communication). A similar loss in weight during the firing of the clays may be inferred from the chemical analyses of the clays (Table 2). The ignition loss in each sample is about 3 to 4 percent of the original weight, except in the sample of expanded material, in which there is no ignition loss. It should be emphasized that the ignition loss does not include any soil moisture, which presumably was driven off by the drying of the samples before determination of the ignition losses. We may infer that the 3 to 4 percent ignition loss shown by the clays represents the water of crystallization in clay and micaceous minerals, the expansion of which as vapor being the principal cause of the expansion of the clays.

There are evidently factors involved in the expansion of clay other than the amount of water available from clay minerals and chlorite alone. Indeed, the amount of expansion decreases fairly regularly with increases in ignition losses in the five samples for which chemical analyses are available, as shown in Table 4. Assuming that the ignition loss is loss of water only, it must be concluded that the total amount of water of crystallization present in a particular clay pellet and available for the production of water vapor does not alone determine how much expansion will occur.

TABLE 4. Relation of amount of expansion and ignition loss of 5 selected clay samples.

Sample number	Ignition loss	Amount of Expansion
CL-12	3.1%	295%
CL-97	3.2	5
CL-98	3.7	195
CL-10	3.9	163
CL-84	4.2	147

A requisite for the expansion of clay is the fusion of the outer surface of the clay pellet before or during the formation of internal gases in order that at least some gas is forced to expand within the clay pellet. Fusion is facilitated by the presence of such fluxes as iron oxide and lime within the clay, and it might be assumed that the more complete the fusion of the outer surface and the lower the temperature at which it occurred, the more gas would be trapped within the clay. The amount of expansion does increase with the total content of possible fluxes in the five clay samples for which chemical analyses are available (see Tables 2 and 4). The leaching of lime during the weathering of the brown clays may be at least partially responsible for the observed difference in expansion characteristics of the brown and gray clays.

Preparation of test samples of lightweight concrete. Four samples of clay from the Sandy River area were prepared for testing their suitability as lightweight aggregate. Two lake clays, samples CL-5 and CL-43, having different particle size characteristics (see Appendix 1), and two marine clays, samples CL-82 and CL-90, were selected for these tests.

Expanded pellets of the four clay samples were graded as to size, following A.S.T.M. specifications for the preparation of coarse aggregates and mixed with sand and Lehigh type II cement. Three 2-inch cubes of concrete were then formed from each batch, all batches consisting of 2.75 parts coarse aggregate, 2 parts sand, and 1 part cement.

Two cubes of the concrete made from each sample were used for strength tests, one after 7 days of curing, the other at the end of 28 days. The third cube was used to measure the density of the concrete.

TABLE 5. Results of tests of lightweight concrete.

Concrete mixture	A	B	C	D	E	F	G	H
Coarse Aggregate	PM-1	PM-2	CL-5	CL-43	CL-82	CL-90	Gravel	Lelite
Workability	Poor	Good	Fair	Fair	Good	Good	Good	Good
Finish	Poor	Fair	Fair	Fair	Fair	Fair	Good	Fair
Segregation	Some	Slight	Some	Some	Slight	Slight	None	Slight
Rodability	Poor	Good	Fair	Fair	Fair	Good	Good	Fair
Bleeding	Slight	Slight	Slight	Slight	Slight	Slight	Slight	Slight
7-day tests								
Damp density, pcf	117.3	110.3	118.3	111.9	107.6	113.3	146.0	122.1
Oven-dry density, pcf	106.2	99.8	*	105.6	97.2	103.0	137.5	111.2
Compressive strength, psi	2510	2480	1680	2510	2640	2870	4260	2720
28-day tests								
Damp density, pcf	125.1	107.7	116.2	110.8	108.0	116.8	146.2	122.0
Oven-dry density, pcf	*	*	*	*	*	*	*	*
Compressive strength, psi	3890	3590	2850	3640	3250	3840	6450	4000

Tests by Thompson & Lichtner Co., Inc., 8 Alton Place, Brookline 46, Massachusetts

* Insufficient aggregate for test

pcf = pounds per cubic foot
psi = pounds per square inch
Lelite = commercial lightweight aggregate

The results of these tests, together with comments concerning the quality of the outer surface of the concrete, the ease of working the concrete mixture, and so forth, are shown in Table 5. Also presented in Table 5 for comparison are the results of the same tests performed on identical test cubes, using a commercial lightweight aggregate and standard gravel as coarse aggregate. Two samples (PM-1 and PM-2) of expanded Monson slate, one fired for 3 minutes, the other for 4 minutes, at about 2050°F, were also prepared, using the same proportions of coarse aggregate, sand, and Portland cement, and the results of the various tests of these materials are also shown in Table 5. Figure 12 shows some of these test cubes, together with the raw materials used in making the coarse lightweight aggregates. Aggregate tests and actual batch quantities of coarse and fine aggregates used in fabricating the test cubes are presented in Appendix 3.

Of course the results of the strength tests shown in Table 5 should not be taken as representative of all Maine clays, but they do indicate that the samples of clay selected produced lightweight aggregates which compare very favorably with one commercial lightweight aggregate. Concrete using the aggregate made from Sandy River clay and Monson slate is slightly lighter in weight

than that made from the commercial lightweight aggregate and has, with the exception of the concrete made from clay sample CL-5, about the same compressive strength.

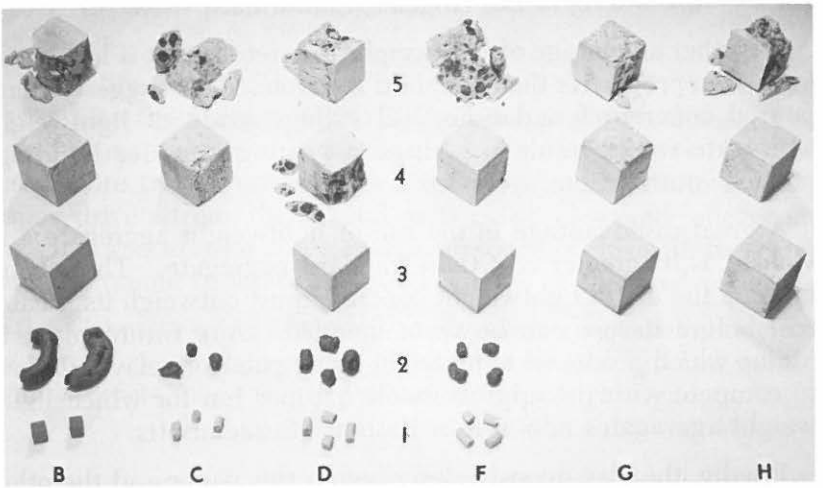

FIGURE 12. Photograph of 2-inch concrete cubes fabricated from lightweight aggregate, before and after compressive strength tests.

Reading Vertically		Reading Horizontally	
Column B	PM-2 (Monson Slate)	Column 1	Raw material
Column C	CL-5	Column 2	Expanded material
Column D	CL-43	Column 3	Untested cubes
Column F	C1-90	Column 4	Cubes used in 7-day tests
Column G	Standard gravel aggregate	Column 5	Cubes used in 28-day tests
Column H	Commercial lightweight aggregate		

Use of lightweight concrete. It is not the purpose of this paper to outline in detail all the possible uses of lightweight concrete and the advantages of using lightweight concrete rather than standard concrete. It would not be inappropriate, however, to mention a few selected examples of uses to which lightweight concrete has been put.

Concrete made from lightweight aggregate has the obvious advantage of lightness, whereas it possesses the strength necessary to support great loads. By reducing the weight of a structure, less structural steel is required in its construction. Trefethen (1955, p. 85) states that over three million dollars in structural steel costs were saved by using lightweight aggregate, rather than

sand and gravel, in the construction of the concrete roadway of the San Francisco-Oakland bridge. According to Johnson (1957), by using $61,000 worth of lightweight aggregate, $180,000 in structural steel costs were saved in the construction of the General Petroleum Building in Los Angeles, California.

A further advantage of lightweight concrete is that it has better insulation properties than standard concrete. It is suggested that poured concrete foundations and sidings made of lightweight aggregate would result in savings in heating costs for buildings of such construction.

A great disadvantage in the use of lightweight aggregate, obviously, is its greater cost than standard aggregate. The advantages in the use of lightweight concrete must outweigh its greater cost before its use can be recommended. Any future plant in Maine which produced lightweight aggregate from clay will have to compete with the approximately $10 per ton for which lightweight aggregates now sell in Boston, Massachusetts.

Finally, the clay deposits described in this paper and the other extensive deposits described by Trefethen (1947) and Goldthwait (1949, 1951) in other parts of Maine represent a practically limitless, readily accessible supply of raw material for the production of lightweight aggregate.

Summary of physical, chemical, and thermal expansion properties of Sandy River clays

The results of and conclusions drawn from the physical and chemical tests of Sandy River clays may be summarized as follows:

1. The majority of the sediments considered in this paper are silt, and not clay, sediments, if classified by the "average" particle size. There is no consistent difference in the particle size characteristics of marine and fresh water clays. Most of the sediments studied are moderately sorted.

2. Most of the sediments tested are plastic over a wide range of water contents.

3. Chemical differences between brown and gray clays are consistent with the view that gray clay weathers to brown clay.

4. Chemical similarities between the Sandy River clays and argillaceous sediments and rocks indicate the clays are the unaltered product of glacial erosion of nearby bedrock. The chemical and mineralogical composition of the clays are related regularly to their particle size, which reflect conditions during deposition.

5. Pellets of clay, fired at about 2000°F for 3 to 4 minutes, expand, on the average, about 130% of the original volume. The finer sediments expand more than the coarser and gray clays expand more than brown clays. Expansion is the result of water vapor driven from the crystal lattices of clay and micaceous minerals and may be aided by the presence of fluxes in the clays which promote fusion of the outer surface of the fired pellets.

6. Concrete using expanded Sandy River clay as a lightweight aggregate compares favorably in compressive strength and weight with concrete made from commercial lightweight aggregrate.

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APPENDIX 1. Color, particle size, and plasticity of Sandy River clays.

Sample number	Locality number	Color	Depth (feet)	Modal diameter (mm)	Median diameter (mm)	Trask sorting coefficient	% clay-size particles	Index of plasticity (%)	Plastic limit (%)	Liquid limit (%)
CL-3	5	Brown	4	.044	.05	2.7	15	19.8	25.8	45.6
CL-4	6	Brown	6-9	.00276	.0042	2.3	46	32.7	26.0	58.7
CL-5	6	Gray	9-12	.0055	.005	2.7	42	13.0	28.0	41.0
CL-6	6	Gray	12-14	.0055	.0065	1.9	26	16.4	25.7	42.1
CL-8	7	Brown	1-3	—	—	—	—	19.0	19.0	38.0
CL-10	9	Brown	2-4	.0055	.0052	2.6	42	16.5	18.5	34.0
CL-12	9	Gray	9	.0055	.0064	3.2	37	11.8	20.0	31.8
CL-13	10	Gray	10-12	.022	.012	2.0	20	12.3	17.7	30.0
CL-14	15	Gray	5-8	.011	.007	3.15	35	—	27.0	—
CL-15	15	Gray	12-21	.022	.01	2.8	29	—	23.0	—
CL-16	18	Brown	5	—	—	—	—	—	35.0	—
CL-18	21	Brown	11	.011	.01	3.72	17	26.1	29.9	56.0
CL-19	21	Gray	18-21	.0055	.0045	2.75	46	13.3	22.8	36.1
CL-20	21	Gray	27	.0055	.0042	3.5	48	—	—	—
CL-22	22	Gray	5	—	—	—	—	—	28.9	—
CL-29	29	Gray	—	—	—	—	—	30.0	19.6	49.6
CL-31	30	Brown	15	.011	.0096	1.96	21	17.8	24.6	42.4
CL-32	32	Brown	6	.0039	.0021	3.15	57	19.6	21.4	41.0
CL-33	32	Brown	25	.0078	.0028	4.46	54	18.0	25.0	43.0
CL-35	36	Gray	13-19	.011	.0067	4.3	38	—	33.2	—
CL-36	36	Gray	10	.0055	.0054	3.6	42	—	—	—
CL-39	Wells	Brown	5	.0039	.0013	—	67	22.8	21.4	44.2
CL-41	44	Gray	—	.011	.01	2.18	19	14.2	22.4	36.6
CL-43	49	Gray	18	.00276	.0033	3.52	54	—	—	—
CL-44	51	Gray	24	.044	.019	2.2	16	—	—	—
CL-46	51	Gray	14	.0055	.0036	2.44	53	—	—	—
CL-47	51	Brown	12	.0039	.0039	3.0	50	—	—	—
CL-48	53	Brown	6	.0055	.0029	2.86	58	—	—	—
TL-49	57	Gray till	3	—	—	—	—	6	9.4	15.4
CL-50	59	Gray	2	.044	.018	2.25	16	9.2	26.0	35.2
CL-53	60	Gray	6-9	.011	.0092	2.35	25	—	—	—
CL-54	60	Gray	12-14	.011	.0079	2.86	34	—	—	—
CL-55	61	Gray	—	.0055	.0034	2.54	55	—	—	—
CL-56	62	Brown	2-4	.011	.0057	3.1	42	—	—	—
CL-57	62	Gray	5-6	.011	.0064	3.16	39	—	—	—
CL-58	63	Gray	15	.0055	.0041	—	47	—	—	—
CL-59	63	Brown	6	.022	.016	1.95	12	—	—	—
CL-60	64	Brown	2	.011	.0072	2.3	36	—	—	—
CL-61	64	Gray	6-13	.011	.0042	3.16	49	—	—	—
CL-62	64	Gray	13-15	.0055	.0039	3.42	50	—	—	—
CL-63	65	Gray	10	.0055	.0033	3.16	58	—	—	—
CL-64	66	Brown	8	.011	.0043	> 2.4	48	—	—	—
CL-67	69	Brown	5	.0055	.0038	> 2.2	51	—	—	—
CL-68	70	Gray	33	.022	.017	> 1.7	—	—	—	—
CL-69	70	Gray	50	.011	.0094	2.8	28	—	—	—
CL-70	70	Brown	10	.011	.0094	2.8	28	—	—	—
CL-72	72	Gray	80	.0055	.0038	3.9	50	—	—	—
CL-73	Brewer	Brown	5	.022	.013	3.86	36	—	—	—
CL-74	Brewer	Gray	10	.011	.011	3.86	37	—	—	—
CL-75	Sidney	Gray	120	.022	.0074	3.10	37	—	—	—
CL-80	73	Gray	27	.0055	.017	6.0	32	—	—	—
CL-81	Gorham	Gray	10	.022	.0052	5.0	45	—	—	—
CL-82	Portland	Gray	6	.011	.0036	3.86	51	—	—	—
CL-83	Gray	Gray	25	.0055	.002	> 4.9	61	20	21	41
CL-84	73	Gray	10	.0055	.0033	2.7	54	—	16.8	—
CL-85	73	Gray	18	.022	.0145	3.04	14	—	—	—
CL-89	73	Brown	3	—	—	—	—	—	25.2	—
CL-90	74	Gray	10	.0055	.0038	2.58	51	11.0	23.8	34.8
CL-94	80	Gray	5	.0055	.0051	3.66	43	11.0	23.0	34.0
CL-97	83	Brown	3	.011	.0074	3.24	36	—	—	—
CL-98	83	Gray	6	.011	.006	3.28	41	12.6	18.4	31.0
CL-102	89	Gray	5	.011	.01	1.92	22	—	—	—

APPENDIX 2. Data relating to expansion of clays.

Sample number	Color	Temperature Range (°F) Beg.	End.	Firing Time Min:Sec.	Expansion-percent original volume Max.	Aver.	Remarks
CL-3	Brown	1900	1900	2:50	—	—40	
CL-4	Brown	2020	2020	2:45	308	216	
CL-5	Gray	1950	1900	2:25	—	76	
CL-5	Gray	2050	2050	3:30	425	321	1/5 exploded
CL-6	Gray	1900	1875	2:40	—	37	
CL-6	Gray	2050	2100	3:30	330	136	
CL-8	Brown	1940	1900	3:00	—	95	3/10 exploded
CL-10	Brown	2000	2050	2:50	—	163	
CL-11	Brown	2075	2075	3:05	453	342	
CL-12	Gray	2010	2050	4:00	430	295	
CL-13	Gray	2025	1980	3:20	242	158	
CL-14	Gray	2050	2050	3:00	295	216	
CL-15	Gray	1950	1920	2:05	—	90	
CL-16	Brown	2025	2040	3:00	—	45	
CL-19A	Gray	1950	1990	6:00	—	97	
CL-19B	Gray	2000	2000	2:40	374	216	
CL-19C	Gray	2050	2025	2:30	320	174	
CL-19D	Gray	2000	2000	1:35	—	39	
CL-19E	Gray	2050	2000	3:30	—	110	
CL-19F	Gray	2050	2040	4:30	190	79	
CL-19G	Gray	2010	2050	5:50	—	120	
CL-19H	Gray	2050	2050	4:00	—	95	
CL-19I	Gray	2050	2000	3:30	427	358	Pre-heated asbestos plate
CL-19J	Gray	2000	2050	7:10	—	137	Used asbestos plate
CL-19K	Gray	2060	2060	1:50	480	314	Unused asbestos plate
CL-19L	Gray	2075	2075	3:00	—	163	Used asbestos plate
CL-19M	Gray	2050	2100	4:40	—	268	Unused asbestos plate
CL-20	Gray	Not recorded		—	—	360	
CL-22	Gray	2050	2050	3:50	137	74	
CL-23	Brown	1900	1900	4:00	—	—15	
CL-25	Brown	2050	2050	3:10	—	5	
CL-27	Brown	2000	2025	3:00	—	95	
CL-29	Gray	2075	2050	3:25	—	110	
CL-31	Brown	1925	1925	4:50	—	16	
CL-32	Brown	2075	2100	2:30	—	240	2/5 exploded
CL-33	Brown	2030	2050	3:40	348	280	
CL-35	Gray	2050	2050	3:10	—	210	
CL-36	Gray	2040	2050	2:00	163	155	
CL-39	Brown	1950	1950	3:00	163	153	
CL-40	Gray	1960	1940	2:25	—	18	Locality 41, Strong
CL-41	Gray	2060	2050	4:00	—	38	Locality 44, Strong
CL-43	Gray	2060	2060	3:00	450	440	Greatest average expansion
CL-44	Gray	1940	1960	3:40	—	18	
CL-46	Gray	1925	1900	2:20	—	96	
CL-46	Gray	2050	2060	2:20	—	240	1/5 exploded
CL-47	Brown	1925	1900	2:05	—	39	1/10 exploded
CL-48	Brown	1950	1900	3:35	—	53	3/10 exploded
TL-49		1940	1920	2:50	—	18	Gray plastic till
CL-50	Gray	1900	1900	3:00	—	16	
CL-54	Gray	1940	1920	2:25	—	13	Locality 60, Wilton
CL-55	Gray	1960	1925	2:40	—	42	
CL-56	Brown	1910	1925	2:40	—	45	
CL-56	Brown	2060 —	Not recorded		—	—	All pellets exploded
CL-57	Gray	2050	2050	3:15	425	310	Locality 62, Farmington
CL-58	Gray	1910	1900	2:55	—	76	
CL-58	Gray	2050	2060	2:30	426	216	2/5 exploded

Sample number	Color	Temperature Range (°F) Beg. End.	Firing Time Min:Sec.	Expansion-percent original volume Max.	Aver.	Remarks
CL-59	Brown	2000-2020	3:00	163	97	
CL-60	Brown	1950-1950	3:10	—	52	
CL-61	Gray	2050-2050	2:55	—	110	
CL-62	Gray	2050-2050	3:00	—	180	
CL-63	Gray	2150-2100	1:35	—	230	
CL-64	Brown	1950-1900	2:00	—	84	
CL-64	Brown	2060-2050	2:05	242	216	
CL-67	Brown	2000-2050	3:00	320	230	
CL-68	Gray	2010-2050	3:25	216	137	
CL-69	Gray	2025-2050	3:25	137	136	
CL-70	Brown	2050-2060	4:20	163	97	
CL-72	Gray	2030-2050	1:55	425	348	Varved clay overlain by till, i.e. compacted.
CL-73	Brown	2000-2030	3:45	—	110	Samples CL-73 and 74 from brickyard in Brewer.
CL-74	Gray	1950-1975	4:00	—	58	
CL-74	Gray	2060-2050	3:00	—	92	
CL-75	Gray	2050-2060	3:00	216	153	Sample from Sidney, Me. Highway Comm. boring.
CL-80	Gray	2010-2025	3:00	418	308	
CL-81	Gray	1960-1940	2:20	—	74	Greater expansion in CL-81 when fired for longer time. (Sample from Gorham, Me.)
CL-81	Gray	1925-1900	4:10	—	163	
CL-82	Gray	1900-1875	2:15	—	84	Sample from Portland, Me.
CL-82	Gray	2050-2050	3:40	426	374	
CL-83	Gray	2050-2050	4:00	—	320	Sample from Gray, Me.
CL-84	Gray	2025-2050	3:00	240	147	
CL-85	Gray	2010-2050	3:00	—	0	
CL-89	Brown	2025	—	—	—	All pellets exploded
CL-90	Gray	2100-2080	2:30	480	370	Locality 74, New Sharon
CL-94	Gray	2050-2050	3:00	163	163	Locality 80, Starks
CL-97	Brown	2025-2025	2:30	—	5	4/5 exploded. Locality 83
CL-98	Gray	2050-2050	2:15	242	195	Locality 83, Norridgewock
CL-102	Gray	2080-2060	2:00	—	97	Locality 89, Chesterville

APPENDIX 3. Data relating to fabrication of concrete test cubes.

Report of The Thompson & Lichtner Co., Inc., 8 Alton Place, Brookline 46, Massachusetts, dated January 30, 1959, to Maine Geological Survey, Augusta, Maine.

TESTS OF NORMAL AND LIGHTWEIGHT
AGGREGATE CONCRETES

Test Number — AA756

Date Received — 1-15-59

Samples — Six samples of lightweight aggregates identified as PM-1, PM-2, CL-5, CL-43, CL-82, CL-90, submitted by Mr. D. W. Caldwell.

Lehigh Type II cement obtained in Boston Market, natural sand and gravel obtained from J. P. O'Connell Company, Boston, 3/4″ Lelite obtained from J. P. O'Connell Company, Boston.

Test Procedures — Aggregates artificially separated as shown below, then recombined so gradations of all aggregates used in concrete mixtures were the same. Crushing of aggregates by hand was resorted to in the case of the aggregates submitted by Mr. Caldwell in order that a sufficient amount of sizes could be obtained. Gradation analyses and unit weight determinations were made in conformity with applicable ASTM Standard Methods. All aggregates were soaked overnight to prevent absorption of mixing water when concrete was batched. All batches were mixed by hand employing proportions by dry loose volumes of one part cement, 2 parts sand, 2.75 parts lightweight aggregate. Slump of concrete for all batches was made to be an estimated 4″ by addition of an adequate amount of mixing water. Darex air entraining agent was added to each batch in proportion of 1.5 oz. per 94 lbs. of cement. Three 2″ cubes were fabricated from each mixture except with aggregate CL-5 for which sufficient material was available for fabrication of two cubes only. Specimens were stored in their steel molds for 48 hours at 70°F, 100% R.H., then were stripped from their molds and remained in the same damp storage until testing.

Results — The following data was obtained:

Aggregate Tests
Gradation analysis, % retained

Sieve	Sand	All coarse Aggregate
3/4″		0
1/2		31
3/8		62
#4	0	95
8	15	98
16	39	100
30	65	
50	85	
100	96	
Fineness Modulus	3.00	6.55

Weight dry loose

Sand	101.0 pcf
3/4″ gravel	90.0 pcf
3/4″ Lelite	41.2 pcf
PM-1	45.1 pcf
PM-2	28.6 pcf
CL-5	38.9 pcf
CL-43	30.5 pcf
CL-82	29.5 pcf
CL-90	31.1 pcf

Actual batch quantities

Mix	Coarse Aggregate	Cement Grams	Sand Grams	Coarse Aggregate Grams	Total Water Grams	Darex cc
A	PM-1	250.1	537.0	330.0	185.0	0.26
B	PM-2	322.5	693.0	270.0	217.0	0.34
C	CL-5	76.5	264.0	87.0	49.0	0.08
D	CL-43	302.0	649.0	270.0	184.0	0.31
E	CL-82	312.6	672.0	270.0	174.0	0.33
F	CL-90	159.3	342.0	145.0	92.0	0.17
G	Gravel	380.0	782.0	1000.0	210.0	0.39
H	Lelite	223.5	481.0	113.5	125.0	0.23

Compressive strength and density tests were made in conformity with applicable ASTM Methods.

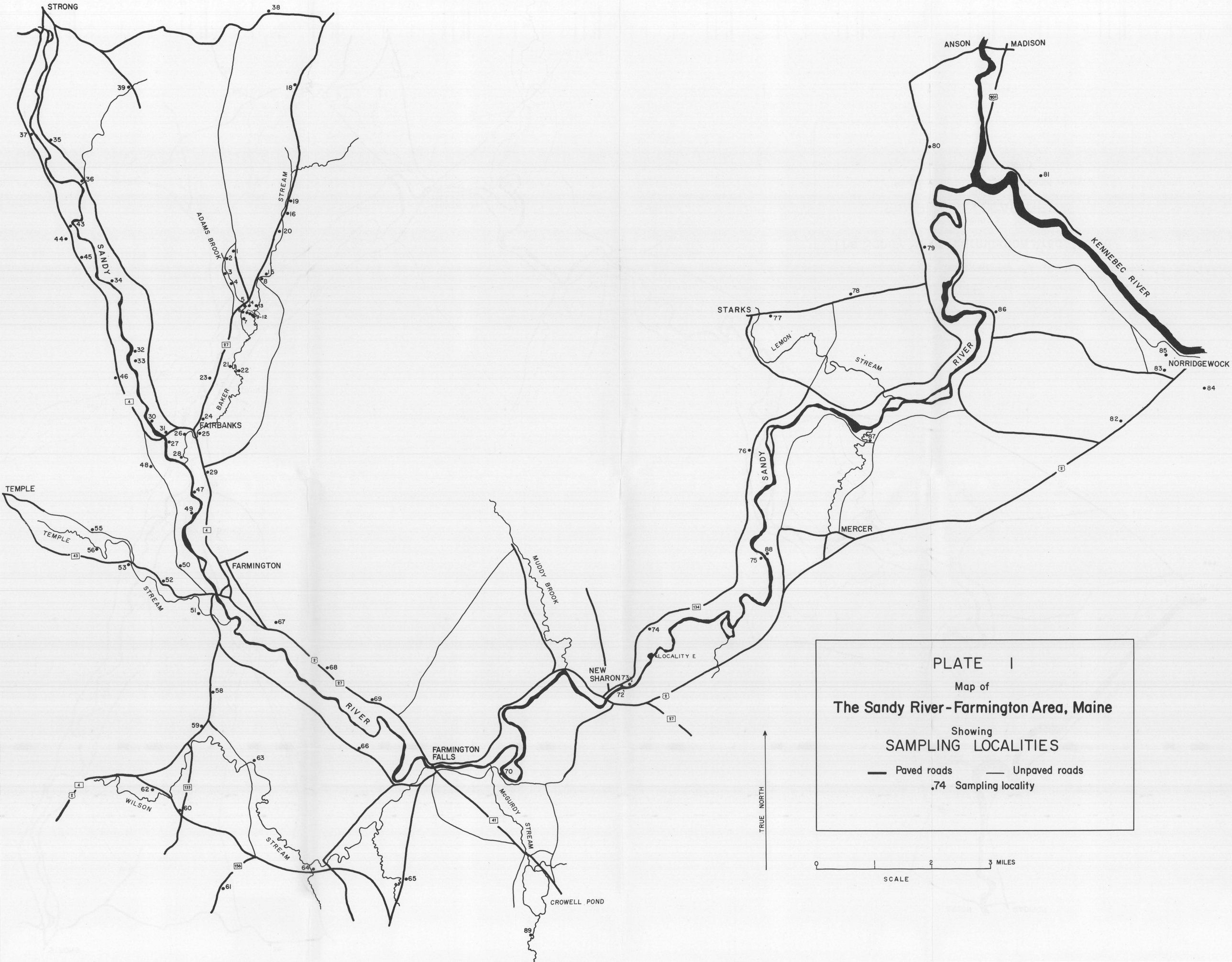


PLATE I

Map of

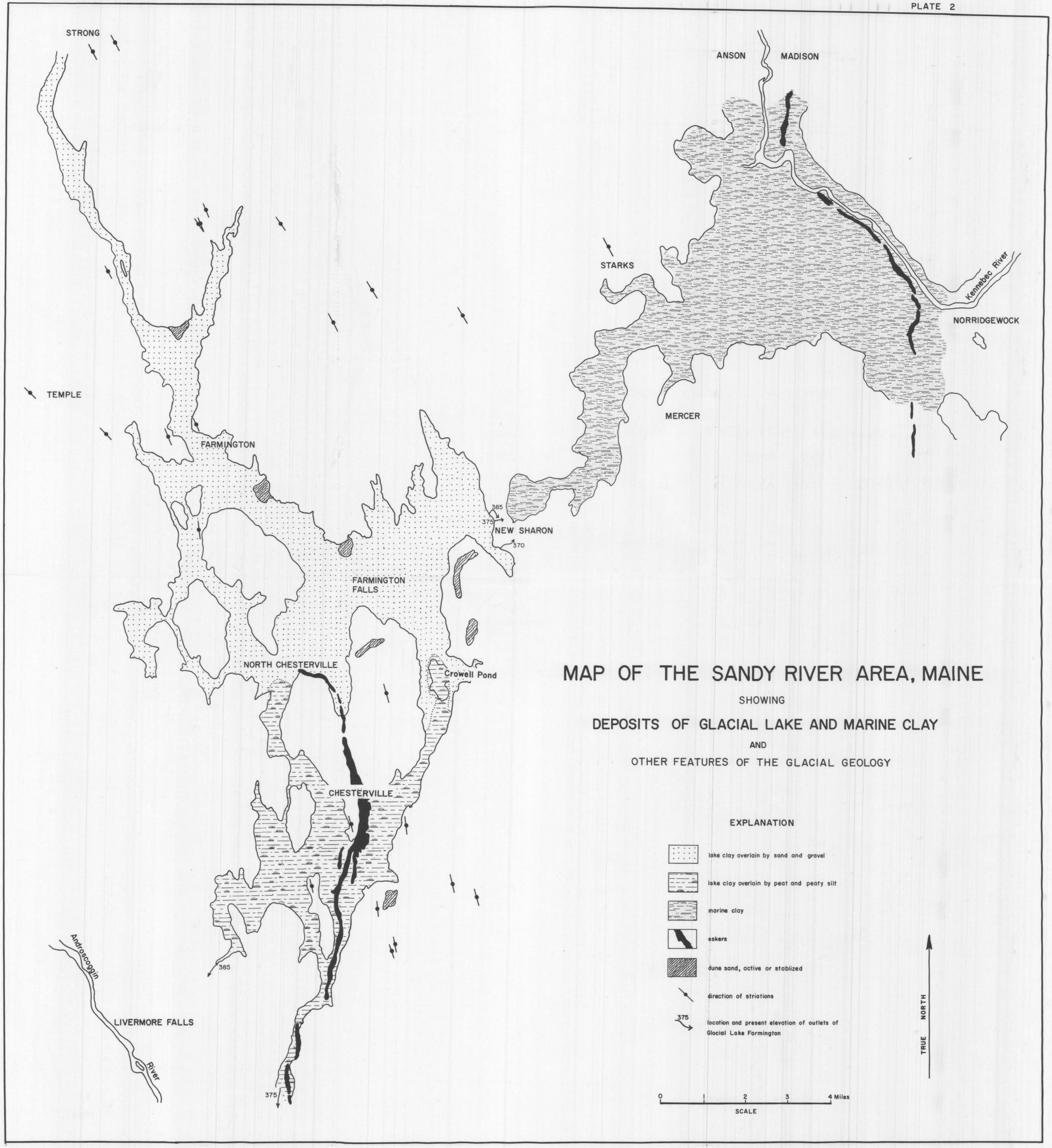
The Sandy River-Farmington Area, Maine

Showing

SAMPLING LOCALITIES

Paved roads — Unpaved roads

.74 Sampling locality


STRONG
ANSON
MADISON
STARKS
Kennebec River
NORRIDGEWOCK
TEMPLE
MERCER
FARMINGTON
385
375
NEW SHARON
370
FARMINGTON FALLS
NORTH CHESTERVILLE
Crowell Pond
CHESTERVILLE
385
Androscoggin
LIVERMORE FALLS
River
375
MAP OF THE SANDY RIVER AREA, MAINE
SHOWING
DEPOSITS OF GLACIAL LAKE AND MARINE CLAY
AND
OTHER FEATURES OF THE GLACIAL GEOLOGY
EXPLANATION
lake clay overlain by sand and gravel
lake clay overlain by peat and peaty silt
marine clay
eskers
dune sand, active or stablized
direction of striations
375
location and present elevation of outlets of Glacial Lake Farmington
TRUE NORTH
0 1 2 3 4 Miles
SCALE

STRATIGRAPHIC SECTION EXPOSED ON SOUTHEAST BANK OF THE SANDY RIVER, NEW SHARON, MAINE

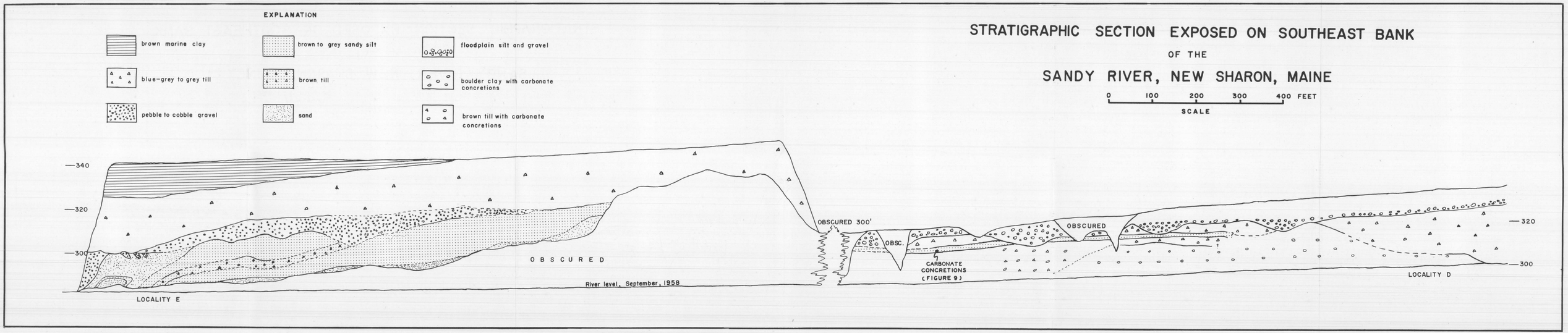


FIGURE 6