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THE SEDIMENTS AND PHYSICAL ENVIRONMENT OF THE SAGADAHOC BAY TIDAL FLAT, GEORGETOWN, MAINE

BY

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by

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Objective

This investigation of the sediments of the Sagadahoc Bay tidal flat was undertaken at the suggestion of the State Geologist of Maine, Dr. Joseph T.efethen, in the hope that the results might be helpful to the biologists of the Maine Department of Sea and Shore Fisheries in their studies of clam productivity and to the biologists of the U. S. Fish and Wildlife Service who are making a systematic study of the ecology and potential yields of the soft-shelled clam (*Mya arenaria*) in Sagadahoc and neighboring bays. The field stage of the investigation lasted from early July to the end of August 1949, during which time I was assisted by W. H. Condon of the U. S. Geological Survey. This report and the accompanying map were prepared in Washington, where the laboratory studies of the sediments were made by T. Woodward of the U. S. Geological Survey.

Acknowledgments

It is a genuine pleasure to acknowledge the help and counsel given on many aspects of this investigation by Dr. Trefethen, State Geologist; R. L. Dow and Dana Wallace of the Sea and Shore Fisheries Department; Dr. John Glud, Dr. R. E. Tiller, Harlan Speare, and Walter Welch of the Fish and Wildlife Service; Dr. G. E.

MacGinitie, Director of the Arctic Research Laboratory; and Drs. W. P. Woodring and H. S. Ladd, both of the U. S. Geological Survey.

Methods of survey

The flat was mapped on a scale of 200 feet to the inch by means of plane table and telescopic alidade. Except to obtain the altitudes of a few points along the shore, which rises abruptly from the flat, all the altitudes were determined by short level shots, generally less than 500 feet. On the upper third of the flat, where the drainage pattern is more complex, altitudes were taken at rod stations approximately 75 feet apart; over most of the rest of the flat the distances between stations were approximately 150 feet. Additional altitudes were determined, however, wherever they were needed for better definition of topographic features that might prove to be of value. During the survey it was discovered that the rocks, particularly along the east shore and at the north end of the bay, contain magnetite, which made our magnetic orientations of the plane table quite unreliable. Consequently, a triangulation net was established and all the plane-table traverses were adjusted to it. The triangulation points are shown on the map. All but the one on the southern Black Rocks Island are marked by small rock cairns.

A line of levels was run by plane table from the nearest permanent bench mark to establish the datum of mean sea level. The datum so determined is, of course, not exact but is probably good to the nearest foot. On the flat, however, we tried to keep altitudes of individual stations within an error of ± 0.2 foot. Probably the easiest reference point to identify is the highest point of the single large smoothly rounded boulder perched on the southern Black Rocks Island in the upper part of the tidal flat. This point was used as one of the triangulation stations and the altitude we assigned is 6.6 feet above mean sea level. The contours on the map are adjusted to that altitude.

The low-tide line at the seaward end of the tidal flat as shown on the map is only an approximation because it is difficult to judge when the tide has reached its lowest stage and impossible to map much of it by plane table in the brief interval of lowest stage. Moreover, the low tides themselves differ more or less systematically by as much as 1 or 2 feet. The low-tide line shown on the map was sketched on two different days, both of which were windy. No particular effort was made to define the low-tide line more exactly because it seemed to have no critical bearing on the study of the clams.

Configuration and drainage of the flat

Virtually all the tidal flat proper lies below mean sea level. From the low-tide line the surface rises only about 4½ feet in its length of nearly a mile. Water drains off this flat continuously while it is exposed between tides. A small part of this water apparently is fresh water that drains out of the porous soil and gravelly glacial deposits on the land adjacent to the marsh upstream from the flat, and from a smaller marsh southeast of the small bay on the east side of the flat. The amount of fresh water is so small that the water flowing in the main channel at the head of the tidal flat tastes distinctly salty even hours after the tide has ebbed. Most of the water draining off the flat is sea water that has either run up into the marsh or soaked into the sandy mud which makes up the flat. The sandy mud is sufficiently porous that it yields its contained water at a slow nearly uniform rate from all parts of the flat that have readily apparent slopes. This ubiquitous source of water, the drainage from the marshes, and the twice daily flood and ebb of a huge volume of tidal water all conspire to produce a complex and distinctive drainage pattern. Abandoned channels and larger, but extremely shallow, depressions remain ponded between tides though they continue to drain very slowly.

A few relatively high areas that consist of rather clean sand drain out to dryness, or near dryness, between tides. These are constructional features built up largely by tidal currents. One of the most notable of these is a rather large, roughly triangular mound on the west side of the flat, filling a southwestward bow of the main channel where it crowds into the southern half of Bed Room Bay. At the highest point this mass of sand rises to mean sea level. Toward the west and northwest this feature is flanked by steep smooth banks of firm, well-drained sand. Southwestward along the east side of the main channel this accumulation of sand tapers out into a natural levee whose crest falls off seaward.

A somewhat comparable "high" sand area rises a little northeast of the center of the flat. This "high" is elliptical; its crest is defined by the -1-foot contour. This high has a relatively steep, short northeastward slope and a very long southwestward slope. Like the "high" on the west side of the flat, it trails out into a low natural levee, which itself has a "high" (1.0 ft. below mean sea level) west of the mouth of the small bay on the east side of the flat.

Only one other high sand area that has these same general characteristics is worth particularizing. This is the rather narrow wedge of sand that lies a little east of the center of the upper part of the flat and just southeast of the sharp double bend in the main channel where the channel crosses the flat. Like the other two sand accumulations described above, this "high" also has a short steep landward (northwestward) slope.

Elsewhere on the flat low ridges of well-drained sand run parallel to drainage channels as short natural levees or extend out as spits in the lee of rock projections or islands. A particularly good example is the spit in the extreme southeastern part of the flat, which parallels the easternmost channel and extends southwestward from a prominent rock head that juts out from the eastern shore. This spit was formed by ebb-tide currents, which run more strongly than the flood-tide currents in that part of the flat. In the northern part of the flat the peak velocities of flood-tide currents markedly exceed the ebb tide currents. Consequently a rounded, massive sand spit has built out northeastward from the northern end of the southern Black Rocks Island.

In addition to the two rather large Black Rocks Islands in the northern part of the flat there are several elongate, but small, nubbins of bedrock that rise a foot or two above the surface of the flat. These are in the southwestern part of the flat and are shown in solid black on the map. Judging by their size and parallelism of strike with that of the large masses of rock exposed around the bay they are probably crests of buried ridges of rock in place. Several similar bedrock "islands" were mapped near the eastern margin of the flat.

Sediments of the flat

Two kinds of sediment make up the great bulk of the flat. These are differentiated on the map. The diagonally ruled areas consist predominantly of soft sandy mud that contains a relatively large proportion of silt and clay. The unruled areas consist predominantly of medium-to fine-grained sand that contains relatively little silt and clay. Almost everywhere the boundaries between these two kinds of sediment are characterized by an insensible gradation from one into the other.

The size distribution of the particles making up these two kinds of sediment was determined by mechanical analysis of one representative sample of each. The sample of the soft mud was collected in the northwestern part of the flat, a little way off the rocky point out which the road runs. The sample of sandy sediment was collected about 200 feet east of the Fish and Wildlife Service log barrier, near the western side of the midsection of the flat. Each sample represents approximately the upper 2 inches of the sediment. Before mechanical analysis the coarse detritus (shells, worm tubes, coarse fragments of sedge and algae, etc.) was screened out. The particle sizes were determined wholly by use of standard sieves. The accompanying graphs (fig. 1) show the size distribution, medians, and degree of sorting of the two representative samples. (The third analysis shown in fig. 1 will be discussed in a later section of the report on regimen of sedimentation.

These two kinds of sediment were mapped, partly because together they make up almost the whole flat but mostly because they appear to be the two kinds of sediment likely to be significant for the clam investigations. The soft mud type represents a relatively quiet environment where the bottom is rarely subject to either strong wave action or strong tidal currents. Hence the finest particles settle to the bottom and accumulate there. The sandy sediment represents an environment where the bottom is frequently (essentially every tide) stirred up by waves and tidal currents so that most of the silt- and clay-sized particles are winnowed out and transported elsewhere. Indeed, it is probable that most of the medium- and fine-grained sand at the surface of the flat is not only stirred up at each tide and moved to and fro but is also forced to migrate progressively upslope toward the head of the bay. (See later section on regimen of sedimentation.)

At a very few small places on the flat the medium- and fine-grained sand has been winnowed out by locally accelerated tidal currents so that only coarse sand remains. Coarse sand, pebbles, and angular cobbles are sparsely mixed in with the normal mud or sand of the flat in a narrow, discontinuous band along some of the rocky margins of the bay, notably along the eastern side in the midsection. Ten or fifteen boulders that range in maximum dimension from about 2 feet to 6 feet were located and are shown by small crosses on the map. Most of these are in the upper midsection of the flat but a few were found along the eastern side and two were found on the western side of the flat barely within the great western bow of the main west channel.

The only other kind of sediment is the medium- to fine-grained, clean, well-sorted micaceous sand that makes up the beaches; notably around Bed Room Bay on the west side of the flat, but also at the north end of the flat and along the southeastern tip. Nearly everywhere the mean high-tide line on these beaches is shown on the map by a dash-dot line. The foot of these beaches is indicated by a dashed line. Generally the foot of the beach is a zone of copious seepage at low tide.

History of sedimentation

During the last glacial epoch Sagadahoc Bay was probably scoured nearly clear of all kinds of sediment and weathered rock by the ice sheet that moved slowly seaward over all the Maine coast. The glacier smoothed off the rocks and rounded over the projecting knobs and angles. But as the ice front retreated, melt-water streams and rivers, heavily loaded with sand and gravel, must have deposited some of their load on the bottom of the bay and filled it up to some undetermined level. Upon this inferred base of glacial outwash rests the whole prism of postglacial and modern sediments. How thick the total filling of glacial, postglacial, and modern sediments is we do not know; nor is it pertinent to this investigation.

It is pertinent, however, to determine, if we can, whether the prism of sediment in the bay is progressively building out seaward and particularly if, on the average, the whole surface of the flat is rising progressively by sedimentation. If the surface is being built up or cut down at an appreciable rate this would probably have a significant effect on the welfare of the clams.

Several lines of evidence have been followed in an effort to determine whether the surface of the flat is becoming progressively lower or higher, or whether it is essentially in a state of equilibrium such that the altitude of any one spot changes cyclically over a long period of time but between rather narrow limits, say a foot or two.

Comparison of the most recent Coast and Geodetic Survey charts (314 and 238) published in 1947, with an early edition of No. 314 first published in 1878 and reissued in 1907 suggests that Sagadahoc Bay has filled enough in that interval to shift the low-tide line in the eastern part of the Bay a little less than a quarter of a mile seaward. Along the western side only a small seaward shift is indicated. Comparison of these charts also indicates that the water between Indian and Kennebec Points has shoaled 2 to 3 feet. Probably not too much dependence should be placed on these figures, however, because the hydrography of such shallow water is not of much importance to navigation, particularly within a bay like Sagadahoc.

The most cogent evidence that the surface of the tidal flat has been built up appreciably in postglacial (probably modern) time was obtained from an assemblage of shells collected at a depth of 20 to 22 inches below the present surface of the flat. Excavation to that depth was made possible through the generous help of Dr. Trefethen and Dana Wallace and the use of the State Geological Survey's gasoline engine-driven pump and well points. Well points driven about 5 feet apart and connected by one hose to the centrifugal pump effectively drained the water out of the sand so that a hole nearly 2 feet deep could be dug. The vertical side walls of the pit stood for some time without support. The sand down to about 20 inches below the surface was homogeneous and essentially barren of shells except for several buried layers of dead Gemmas and the present-day Gemmas in the uppermost inch. Myas, of course, were found in the uppermost 6 or 8 inches. Between 20 and 22 inches from the surface, however, old, chalky but firm and well-preserved shells were plentiful. The excavation was made about midway between the southern end of the southern Black Rocks Island and the west margin of the flat.

The assemblage of old shells collected from the bottom of this pit were studied by Dr. H. S. Ladd of the U. S. Geological Survey. His brief report is quoted in full.

"Shells are dull and chalky, and many are worn. The condition of some is suggestive of heavy and prolonged wave action. For example, there is a single fragment of Spisula solidissima--the heavy umbonal fragment is 3 inches long, the same valve when the animal lived must have measured 6 inches across. One of the larger Myas is worn but the others, including a number of thin immature valves, are unworn and unbroken. Intertidal heavy-shelled gastropods show evidence of wear, the largest specimen of Thais lapilla being reduced to a part of the body whorl--the spire and much of the body whorl neatly trimmed away along with the end of the columella and the edge of the outer lip. The largest specimen of Polinices heros has a worn outer lip and had evidently been rolled about before being buried; smaller examples of this species show still more evidence of wear. Many of the echinoid spines are incomplete and the pointed ends of some are distinctly rounded but this rounding may have occurred prior to the death of the animal; no fragments of echinoid tests were found. Gemmas are abundant but the shells have lost most of their color and the exteriors of the valves show extensive pitting and scaling. A single valve of Astarte castanea, though chalky, appears fresher than the other bivalves and shows no evidence of wear. In addition to the shells the collection contains several chips of schistose rock, and slivers of fairly fresh but water-worn wood, one or two seeds, fish bones, and pieces of charcoal.

"Clams appear to form a more important part of the fauna than do the gastropods. The Myas are the most abundant of the larger species and the tiny Gemmas outnumber all other species. The number of species of gastropods, however, is approximately the same as that of the pelecypods.

"Some of the shells probably lived at or below low-tide level. In this group falls the big Polinices heros. This species has been collected alive from low tide to depths greater than 200 fathoms, but it should be remembered that the heavy shell is nearly spherical and could be rolled across a flat for long distances without being badly worn. The _Astarte castanea_ has been dredged alive from 5 to 65 fathoms and it is also known to occur alive at low-water mark. Specimens are occasionally found on beaches after heavy storms. The occurrence of this single unworn valve may be quite significant for it was probably derived from the edge of the tidal flat and probably was not transported an appreciable distance before being buried.

"Most of the species are clearly intertidal and might have lived almost anywhere on the flat. In this group fall the Myas, the Gemmas, the Macomas, the _Spisula_, the mussels, a razor clam (_Ensis_), and a number of small forms that have not been identified. The robust shells of the rock-clinging gastropods such as _Thais_ could have come from near shore or from boulders or outcrops on the flat.

"The commonest gastropod is a tiny species measuring only 2 to 3 mm in diameter. These delicate shells probably belong to the fresh-water _Paludestrina minuta_. This species is known from Labrador to New Jersey, but it is a close-to-shore species, being found on seaweeds at about high-tide level, in salt marsh pools, and on threadlike plants that grow in ditches and brackish pools about marshes in company with _Littorina_. The shells are so thin and delicate that when filled with air they could be transported like bubbles for long distances without breaking. The surprising thing is their abundance in the sand, some 200 occurring in the small sample sieved. These shells, unlike the sand grains you recorded, moved seaward."

About all that need be added to Dr. Ladd's report is that assemblages of shells comparable to this are not found anywhere on the Sagadahoc Bay flat, even out at the low-tide line or in any of the channels whose bottoms are readily visible at low tide. The Fish and Wildlife Service biologists found the tiny gastropods, which Dr. Ladd describes, to be extremely abundant in the upper, muddy sections of the flat; often occurring well over 200 per square foot. They seem to be very uncommon in the other sandier parts of the flat. A few Polinices shells, however, were found on the outer part of the flat near the low-tide line but they were not perceptibly abraided by wave action. Shells of the razor clam also were found near the low-tide line. The chalkiness of the shells indicates that the animals had been dead for some years. Certainly they are much older than animals now inhabiting the flat or the shoal water just below low-tide line.

It appears to be a fair inference that this assemblage of shells was abraided by the waves at what was apparently the low-tide line at the time. In other words, since they accumulated there Sagadahoc Bay has filled with so much additional sediment that the low-tide line has moved seaward about 3,000 feet. Also the surface of the flat has built upward above these old shells 20 to 22 inches.

Evidence from Gemma shells.- Layers in which the shells of Gemma gemma are abundant were observed at several levels below the surface of the sandy mud where Gemmas now live in profusion. Such layers indicate beyond doubt that the surface of the flat has built progressively upward over a period of many years. Each buried layer of Gemmas represents a stage in the ecological history of the flat when conditions were favorable for them to prosper, much as they now do. Evidently conditions highly favorable to Gemmas recur at relatively long intervals. To judge from the stratigraphic evidence of the Sagadahoc Bay flat Gemmas are either uncommon or exceedingly rare between these times of great abundance.

An attempt was made at the end of the field season to trace these buried layers of Gemma shells seaward along the long axis of the flat. A series of short cores were taken from the vicinity of the southern Black Rocks Island in the upper part of the Bay south nearly to the low-tide line. These cores were taken by driving a piece of 1-inch pipe into the sand. Side-wall friction was evidently so great that we obtained cores only about one half to three quarters the depth of penetration. Compaction of the sand probably accounted for a relatively small percentage of the shortness because sand of that composition has a rather small coefficient of compression.

About all that can be said of this attempt is that it demonstrated that in the central part of the flat there are at least four buried layers of Gemma shells, the uppermost of which is roughly 10 or 12 inches below the present surface. The other three lie below that one at intervals of 1 inch to several inches. Our evidence is not adequate to tell whether these represent four extensive layers or whether they represent discontinuous thin lenses. The cores did show, however, that the buried Gemma layers thin down and disappear seaward; no Gemmas were found in the several cores taken close to the low-tide line. Living Gemmas are also rare or absent from the surface of the flat near the low-tide line. Only one of the buried layers appears to represent as great a density of Gemma population as now exists at the surface of the flat. Also several of the cores showed that between the two lowermost layers of Gemma shells the layers were not sharply defined; instead the shells were scattered in fair numbers throughout the sand between the shell layers.

It would be interesting, and perhaps significant for the clay investigations, to know what factors in the ecology of the tidal flat determine these sudden climax developments of Gemma populations. Possibly the present profusion of Gemmas was induced by the abnormally warm and dry weather that has prevailed in that part of Maine since the spring of 1946. (See fig. 2.) This suggestion is based on the assumption that Gemmas have become abundant only in the past 4 years. There is no direct evidence for this, but the virtual absence of dead Gemma shells from the sand below the zone of living Gemmas indicates that their climax development must have come about within a comparatively few years. The suggested relationship between Gemma climaxes and the warm dry weather also involves the pure speculation that Gemma populations are decisively favored by higher-than-average temperatures and less-than-average rainfall. Is it possible, for example, that Gemmas are among those mollusks that are adversely affected by fresh water and therefore thrive and multiply profusely during summers when there are few or no heavy rains to drench the flat at low tide? Gemmas feed actively between tides in the tiny pools of standing water trapped in the troughs of the sand ripples on the tidal flat. Surely heavy rains would greatly decrease the salinity of these small pools.

Evidence of living Myas.- If clams dig themselves in to a terminal depth and thereafter remain fixed in that cavity for the remainder of their lives they should provide an index to progressive changes in the thickness of the sediment above them. If the sediment of a tidal flat is neither being eroded or being built up by deposition, mature clams of all ages and sizes should be found at approximately the same depths below the surface. If the overlying sediment is being eroded, and therefore thinned, the oldest and largest clams should be nearest to the surface and the younger ones at progressively greater depths. But if the sediment is accumulating then the largest and oldest clams should be found at the greatest depth and successively smaller (and younger) clams should be found at progressively shallower depths - that is, up to a minimum, which should be the terminal depths for Mya in that particular kind of sediment. To test this theory Dr. Tiller and his associates very obligingly measured the depths, sizes, and apparent ages of 60 mature Myas from the Sagadahoc flat. Ninety five percent of these came from depths of 6 inches to 9 inches, inclusive. The distribution and ranges in size (length in millimeters) and apparent age (in years) are as follows:

Depths in inches	6		6.5		7		7.5		8		8.5		9	
	Size	Age	Size	Age	Size	Age	Size	Age	Size	Age	Size	Age	Size	Age
	59	5	65	7	62	6	73	8	60	7	98	13.5	76	9
	61	6	68	7	71	7	73	8	68	7			85	9.5
	72	8	74	8	74	8	78	8	75	9			86	10
	72	8	74	11	76	8	81	9	78	9			94	11
	74	9	81	11	76	8	95	13	85	9.5			95	11
	76	10	88	12	78	8	98	14	87	10			98	12
	87	10			79	9			87	10			100	13
	87	10			80	9			89	11				
	89	13			80	9			92	11				
					80	9			94	12				
					81	9			95	12				
					82	10			101	12				
					90	11								
					97	11								
					97	11								
					98	13								

In the accompanying graphs (fig. 3) the median sizes and median apparent ages of the clams are plotted against the depths at which they were found. The number of items in some of the groups is small and, considering the range of the values within each group, the medians from these smallest groups are probably not of much statistical significance. The median lengths for the clams taken at depths of 6, 7, 8, and 9 inches represent the largest groups and these plot as a nearly straight line, showing a progressive increase in size with depth. The medians of the apparent ages show an increase with depth, but it is less regular.

Controlled experiments by the Fish and Wildlife Service biologists tend to show, however, that clams of different sizes when replanted dig in to depths that are proportionate to their sizes. This is, of course, independent of length of time buried or the rate of sedimentation (or erosion) of the mud in which they live. Various sized clams, planted at the same time in laboratory tanks, showed that larger clams dug in to greater depths than did the small clams. These clams, however, failed by about 3 inches to return to as great depth as those from which they were originally dug but the size-depth ratio under laboratory conditions was roughly the same as under original conditions. This 3 inch discrepancy might be explained either by accumulation of sediment on the flats or greater compactness of the laboratory sediment as compared with that on the tidal flat.

Judging by the few data presented on the size-depth ratios of clams in the flat, however, it is doubtful if this part of the flat is building up fast enough to have a bad effect on the clams.

Evidence from recollections of residents.- Mrs. P. K. Rose, who has been coming to Sagadahoc Bay for some 30 years, has written me the only piece of evidence of this kind that I have. She recalls a natural arch or "bridge" of rock rising above the flat at the extreme northern end of the flat. She wrote "We used to crawl under this on our hands and knees and play store behind it, the bridge itself being proper height for the counter. It would now, some 30 years later, be impossible for a child to crawl under."

Evidence from boulders.- The bedrock that rises from the margins of the flat and most of the boulders on the flat support a great abundance of mussels (Mytilus) in the zone a foot or two above the level of the flat. If the surface of the flat were rising by sedimentation there should be dead mussel shells on the rocks buried below the present surface of the flat. Digging around several of the boulders, however, revealed none. I did not dig around any of the bedrock masses or nubbins that rise out of the flat.

Evidence from sediment stakes.- Two 2-inch-square stakes were driven into different parts of the flat so that their upper surfaces were flush with the sediment surface. No decisive changes in the level of mud flat were detected by means of these stakes in the 6 weeks that they were observed.

Regimen of sedimentation

Three dominant factors govern the transportation of sediment to the Sagadahoc Bay tidal flat and along its surface. These are waves and wave-generated currents, tidal currents, and the process of sand flotation.

Waves.- Waves coming in from the open ocean have a general tendency as their bottoms touch the sea floor to stir up the sediment and move it back and forth. As the waves come into progressively shallower water they throw more and more sediment into suspension. The tops of such waves rise and are thrown forward at an accelerating rate, the net effect of which is to move sediment thus thrown into suspension progressively forward despite its to-and-fro motion. It seems probable that waves, particularly waves generated by big storms on rising tides, are primarily responsible for the construction of the extensive mud flats of Sagadahoc Bay in the thousands of years since the continental glaciers melted away. The same process continues today, bringing in from the sea floor the medium- and fine-grained sand that makes up the bulk of the flat. The streams entering the head of the bay bring in virtually nothing but organic detritus as their water is filtered through the sedges of the long marshes upstream.

Tidal currents.- Tidal currents are strong and play a significant role in determining the configuration of the surface of the tidal flat. Flood-tide currents bring upslope an abundance of fine mineral particles and organic detritus, most of which settles to the bottom before the tide ebbs. The average tidal range is about 9 feet, which means that there is a huge prism of water moved into and out of the bay with each tide. Locally both ebb- and flood-tide currents scour deeply in channels, especially where they are constricted by bedrock masses and islands. Where the tidal currents slacken abruptly they deposit considerable quantities of sand. These are the sand "highs" described earlier in the report under the heading "Configuration and drainage of the flat." It is possible that these sand "highs" build up rapidly enough to be detrimental to the clams.

In a few places the surface of the flat has recently been lowered by erosion so much and so rapidly that clams were exhumed and died or were destroyed by predators. Such an area was observed about 400 feet east of the northern Black Rocks Island where a sharp double curve of the main channel is about to be abandoned in favor of a more direct and shorter course southwestward from the top of the S curve. There, where ebb-tide currents short-cut the double bend, they have recently lowered several hundred square feet of the surface 6 or 7 inches, and dead clams are exposed in their normal living positions. In other areas where tidal current scour has lowered the surface only a little, worm tubes have been partially exhumed.

No measurements of the tidal currents were made, but in a few places the velocities of the currents were estimated by timing the drift of free-floating Ulva plants past the length of a 13-foot stadia rod. On an incoming tide when the water that was flowing over a level surface in the upper part of the flat was about 8 inches deep the estimated rate of flow was 1.3 feet per second. In the shallow main channel the current on flood tide was estimated at about 2½ feet per second. The ebb-tide currents in the upper portions of the flat at comparable stages of the tide have velocities estimated to be about half those of the flood tides. This may also be generally true over all parts of the flat, though evidence of such a marked difference was observed only at one place near the seaward end of the flat.

Evidence that the flood-tide currents greatly exceed the ebb-tide currents is provided by the scour pits and sand "tails" around objects that rise above the surface of the flat, such as boulders or sod clumps. The strong flood-tide currents scour out crescentic hollows on the seaward sides of such obstacles and pile the sand up in elongate mounds or long tapering mounds pointed up the flat. The fact that such features are not reversed by the ebb-tide currents shows that the ebb currents are decidedly slower.

On the map arrows indicate the direction of flow of tidal currents. Most of these indicate which direction the water flowed in draining off the flat. A few that point northward at obstacles or that point upstream represent the direction of dominant flood-tide currents. Flood- and ebb-tide currents are not otherwise distinguished. Most of these ebb-tide current directions were determined by measuring the compass bearing of marks in the mud made when drifting seaweed (predominantly Ulva latissma) dragged along the bottom. Ulvas that had become stuck in the mud trailed out parallel to the ebbing current and thus provided another means of measuring current direction. Locally Ulvas settled completely unoriented. In these areas, represented by small open circles on the map, there was essentially no current as the water drained off.

On the map also are shown a considerable number of short lines that represent the axes of the crests of ripple marks. In general they lie transverse to tidal and wave-generated currents. Most of them were produced by waves, though locally strong currents produced highly asymmetric current ripples. The oscillation ripples are symmetrical, sharp crested, and were produced by waves alone. Most of the ripples are asymmetric and the side having the steepest slope is shown on the map by a pointed node at the middle of the axis line. Such ripples have been made asymmetric by the action of relatively weak tidal and wave-generated currents.

Flotation of sand.- The advancing edge of each incoming tide picks up a very considerable quantity of sand and silt which it supports on the surface film. At the advancing edge of the water as much as half the water surface is coated with sand. Probably, on the average, the leading 10-foot band of water has about 10 percent of its surface covered by sand, but stringers and patches of sand extend back 50 feet or more from the leading edge. How far up the flat this floating sand is carried depends largely on how much the water surface is rippled by the wind. Ripples and waves break the surface film and let the sand sink. This is almost wholly a one-way process because the sand generally sinks long before the tide turns. The thin retreating wedge of water draining off the flat lays down whatever sand may still be floating. Sand flotation is probably a significant factor in the aggradation, or up-building, of the flat. In fig. 1 is given a mechanical analysis of sand and silt collected from the water surface as the tide advanced over the southern half of the flat. This sand is much like the sand that makes up so much of the flat, but it contains less medium-grained sand and more very fine sand. It also contains more mica 5.3 percent as compared with 1.7 percent in the average sandy mud designated sample No. 2 in fig. 1. Fine particles and mica are thus selectively transported up the flat by flotation.

Flotation operates not only on the outer sandy parts of the flat but also along the upper reaches of the flat where the surface sediment contains an abundance of clay-sized particles and floculent organic matter. The advancing wedge of water there carries a scum of silt and organic matter that is blown into a froth by the air bubbles escaping from the numerous worm tubes.

The fact that the sand floats readily means that it is coated with a thin layer of some substance that is difficultly wettable. Preliminary chemical tests in the Chemical Laboratory of the U. S. Geological Survey suggest that this coating is a metallic soap, or a mixture of metallic soaps. Such soaps are known to occur in near-shore marine sediments and probably are derived from the interaction of organic acids which, in turn, are derived from decaying organic matter ~~and reaction~~ with the magnesium and calcium ions of the sea water. Additional samples of the floating sand, however, need to be analyzed before the coating material can be surely identified.

Conclusions and suggestions

The Sagadahoc Bay tidal flat consists predominatly of two kinds of sediment: rather well sorted medium- and fine-grained micaceous sand that contains about 0.2 percent of organic matter (exclusive of annelid worms and larger organisms) and medium- and fine-grained micaceous sand admixed with a considerable quantity of silt and clay-sized particles. The clayey sediment contains nearly 2 percent of organic matter (exclusive of annelid worms and larger organisms). Clams appear to thrive in both kinds of sediment though they are more numerous in the clayey material. Evidently the differences in the kinds of sediment in this flat do not constitute a critical or limiting element of the physical environment of Mya arenaria.

Several lines of evidence indicate that the surface of the tidal flat is building up. The rate of aggradation is not known, but apparently it is not so rapid as to be a serious impediment to the welfare of the clams. Locally, however, sand is building up into mounds and ridges at a rate that may be deleterious to clams; but such areas, however, make up a negligible percentage of the whole flat.

In a few small areas (a few hundred square feet) near main channels the level of the flat has recently been lowered 5 or 6 inches by erosion. In these areas the clams have been exposed and killed.

Apparently neither sedimentation nor erosion are now playing significant roles in the ecology of the Myas on the Sagadahoc Bay flat.

Excavations into the upper 2 feet of sediment in the sandy portion of the flat revealed several thin layers of Gemma gemma shells. These layers, one half to about one inch thick, are separated from one another vertically by sand that is nearly barren of Gemmas, or that contains a perceptibly smaller number of them. Each layer represents a dense population of Gemmas that appeared suddenly and after a relatively few years died out about as suddenly. A comparable dense population of these mollusks (25 per square inch) now inhabits the surface of the sandy portion of the flat. Presumably the present inflorescence of Gemmas began only a few years ago. The present climax population of Gemmas may have been induced by the abnormally dry, warm weather that has prevailed in that part of Maine since the spring of 1946.

What effect does such a dense population of surface-feeding mollusks have on the Myas? Do they compete with Mya for food? Do the Gemmas destroy, or starve out, the larval Myas as they settle down on the flat? The ecologic significance and causes of the dense Gemma population appear to be fruitful lines of inquiry in seeking explanations for the virtual absence of clam spat from the sandy portion of the flat.

In observing the factors that tended to inhibit erosion I was struck with the great abundance of annelid (?) worm tubes, particularly in those parts of the flat where Gemmas did not abound. In many areas worm tubes are so close together they resemble, in section, the palisade cells in the cross section of a leaf. Such worm tube "mats" are rather effective in preventing scour in the same way that impacted mats of Enteromorpha are. But it seems to me so dense a population of worms might be playing a much more significant role in the ecology of Mya. Is it possible that these surface-feeding worms are destroying, or starving, the Mya larvae as soon as they settle to the bottom? And is it possible that they are competing with the adult Myas for food?

If my inferences are correct about the feeding habits of Gemma and the annelid (?) worms it appears desirable to remove the Gemmas and annelid (?) worms from small test areas to observe the set of clams where neither of these competitors (or predators) is present. If the Gemmas prove to be deleterious then it would be worth while to study the stratigraphy of the buried Gemma layers and also the environmental controls of Gemma to learn what are the natural causes of Gemma infestations.

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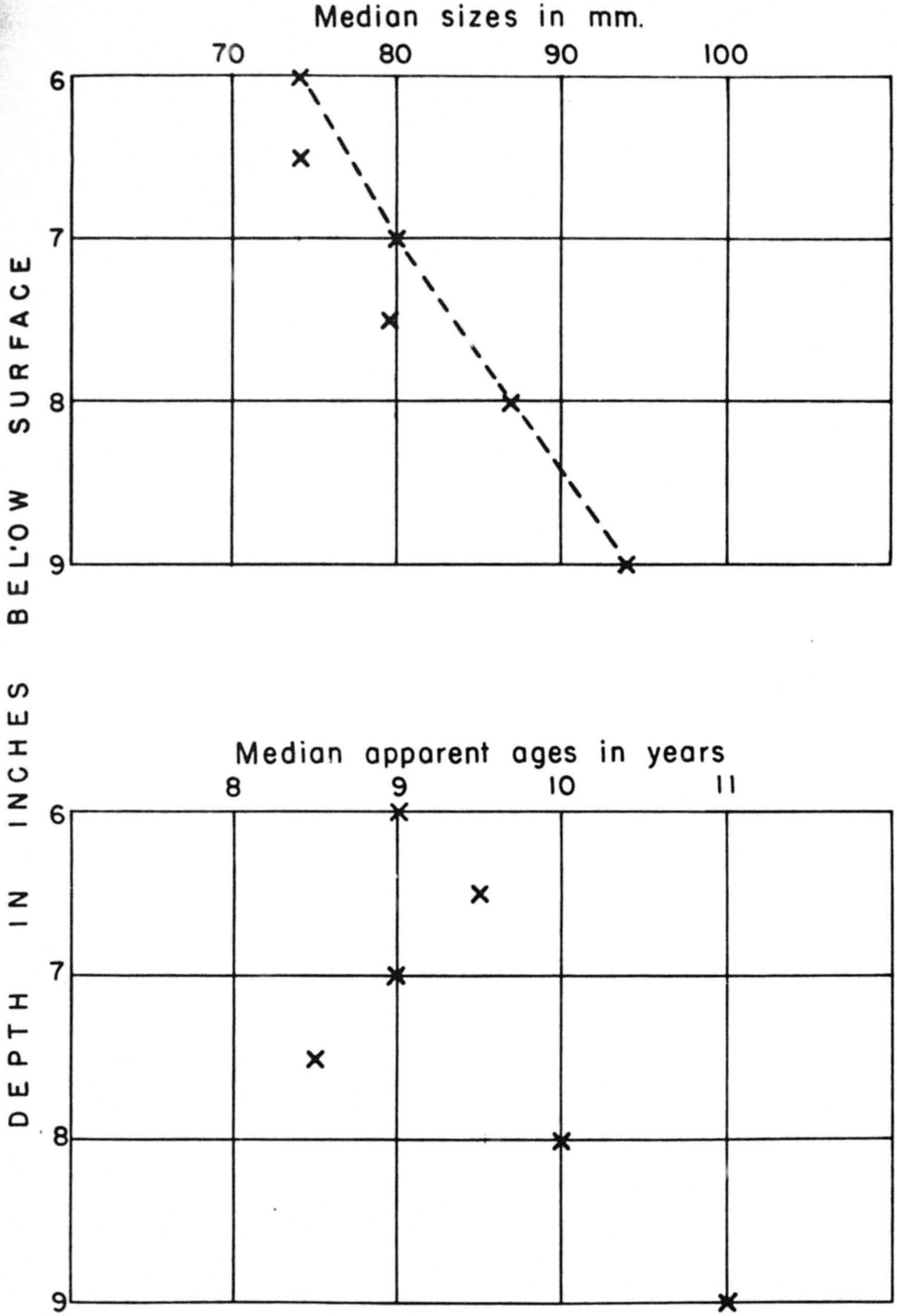
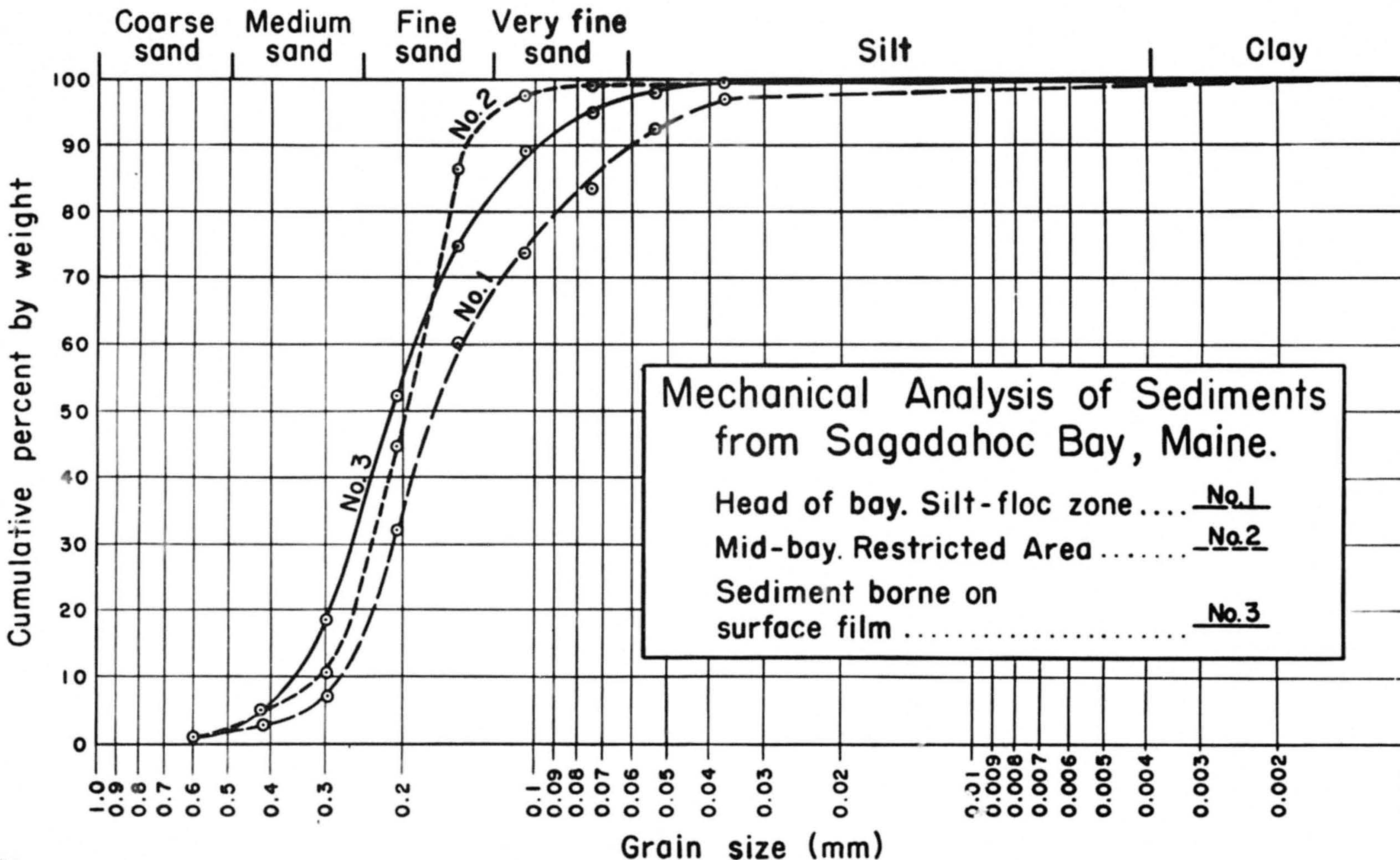


Fig. 3. Depth-size and depth-apparent age relationships in living Moyas in Sagadahoc Bay tidal flat.


Coarse sand
Medium sand
Fine sand
Very fine sand
Silt
Clay
Cumulative percent by weight
0
10
20
30
40
50
60
70
80
90
100
No.1
No.2
No.3
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
Grain size (mm)
Mechanical Analysis of Sediments from Sagadahoc Bay, Maine.
Head of bay. Silt-floc zone No.1
Mid-bay. Restricted Area No.2
Sediment borne on surface film No.3

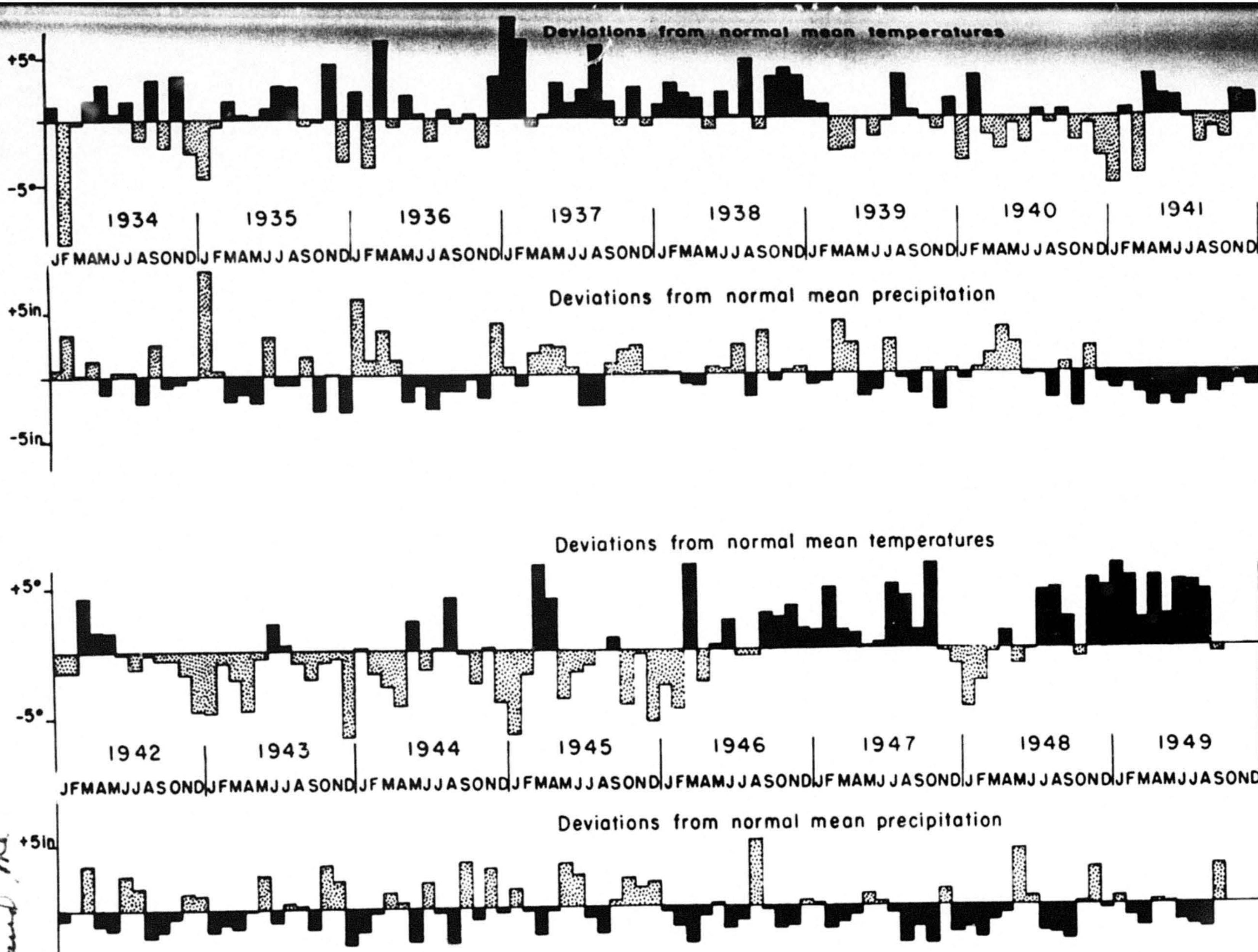
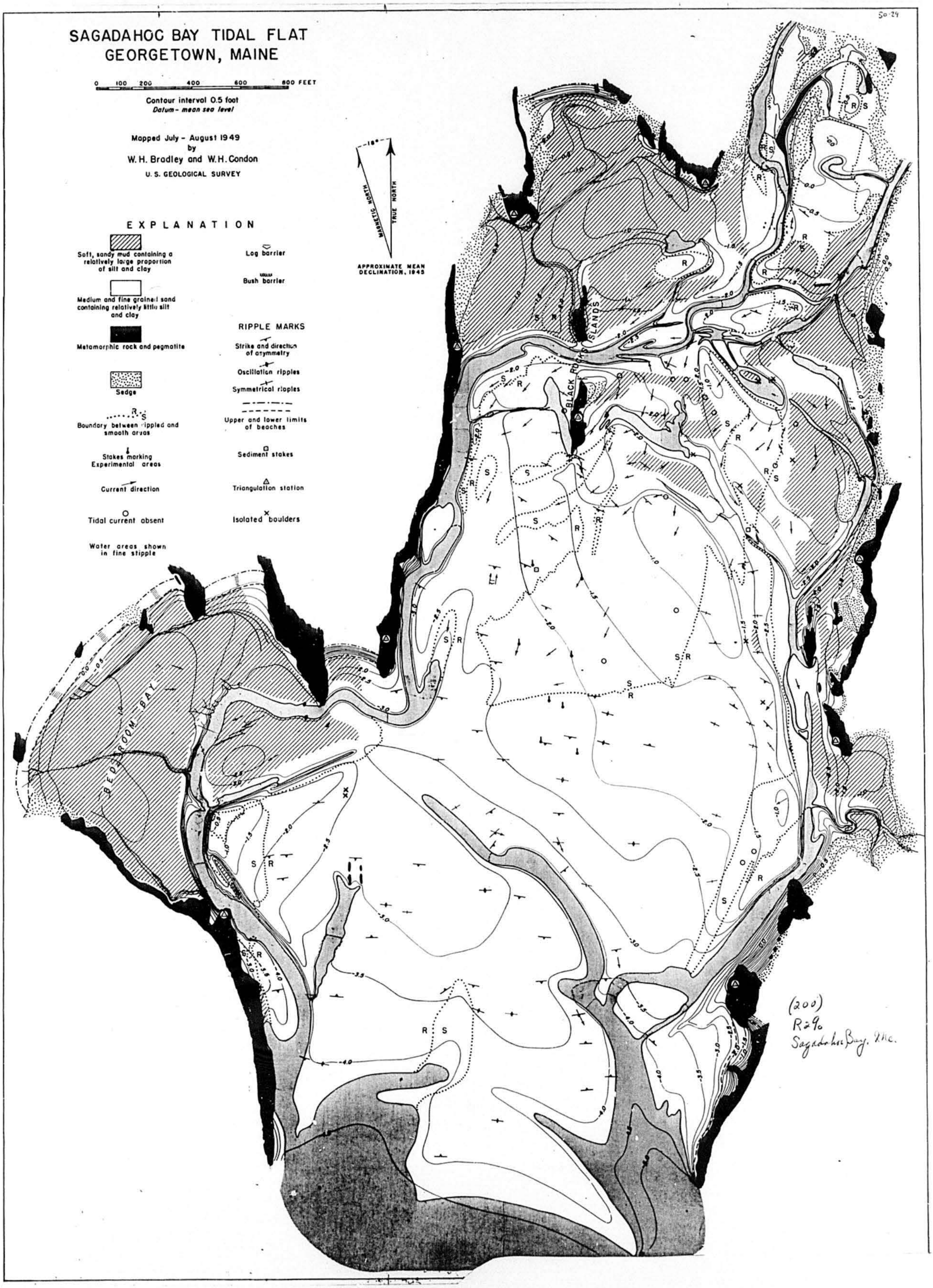


Fig. 2 Deviations from normal mean temperatures and precipitation, Portland, Maine.

30

(200)
P240
Portland Me.


SAGADAHOC BAY TIDAL FLAT
GEORGETOWN, MAINE
0 100 200 400 600 800 FEET
Contour interval 0.5 foot
Datum - mean sea level
Mapped July - August 1949
by
W. H. Bradley and W. H. Condon
U. S. GEOLOGICAL SURVEY
MAGNETIC NORTH
TRUE NORTH
APPROXIMATE MEAN DECLINATION, 1945
EXPLANATION
Soft, sandy mud containing a relatively large proportion of silt and clay
Medium and fine grained sand containing relatively little silt and clay
Metamorphic rock and pegmatite
Sedge
Boundary between rippled and smooth areas
Stakes marking Experimental areas
Current direction
Tidal current absent
Water areas shown in fine stipple
Log barrier
Bush barrier
RIPPLE MARKS
Strike and direction of asymmetry
Oscillation ripples
Symmetrical ripples
Upper and lower limits of beaches
Sediment stakes
Triangulation station
Isolated boulders
BLACK ROCKS ISLANDS
BEDROOM BAY
(200)
R29
Sagadahoc Bay, Me.