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SUMMARY

of

The Massachusetts Coastal Mineral Inventory Survey

Massachusetts Department of Natural Resources
Division of Mineral Resources

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Approved by Alfred C. Holland, Purchasing Agent

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INTRODUCTION

The legislative mandate of the Division of Mineral Resources is to determine the nature of Massachusetts' offshore mineral resources and the environmental effects that the removal of these minerals would have.

In the late spring of 1972, Raytheon Company Submarine Signal Division, under contract to the division, completed a marine geological survey of Massachusetts Bay. The first portion of this survey was a reconnaissance of the entire area between Cape Ann and Brant Rock using subbottom profiling and side scan sonar. From this information, a more detailed survey and sampling program was carried out to delineate potential areas of economic deposits of sand and gravel using acoustical methods, grab sampling, underwater photography and vibracores.

A total of 500 lines miles of acoustic geophysical surveying was accomplished along with one or more cores at 45 sites, grab samples at 66 sites, and 103 bottom photographs. Analysis of the acoustic records, samples, and photos by Raytheon Company formed the basis of information presented in the Final Report of Massachusetts Coastal Mineral Inventory Survey which is summarized below. Analyses showed the location of 15 offshore sites in the bay which could be mined commercially for sand and gravel if deemed environmentally feasible by the division.

The program was carried out by C.F. Willet, Dr. David Cook, David Bell, L.C. Britton, and S. Sternberg of Raytheon Company, Robert Blumberg, Richard Wilkins, and Joseph Jackimovicz of the Division of Mineral Resources, B. Brasher of Alpine Geophysical, W. Wood of Sea Tech, Inc., W. Van Horn, who captained the M/V Atlantic Twin, and Don Phipps and J. Phipps, who captained the M/V Phipps. Special assistance was provided by Dr. John Schlee and Dr. Robert Oldale of the U.S. Geological Survey in planning and evaluating the sampling and survey portions of the project. This summary of the Coastal Mineral Inventory was prepared by Loren Setlow of the Division of Mineral Resources.

MASSACHUSETTS COASTAL MINERAL INVENTORY SURVEY

Subsystems Descriptions

Operations

Operations were divided into two distinct phases. Phase I was planned and carried out as an acoustical reconnaissance operation from which an optimum allocation of resource could be made for Phase II.

Subsystem Descriptions

Acoustic operations were carried out from on board the motor vessel WALTER E. PHIPPS, a 60-foot steel hulled vessel with 16 ½-foot beam and 6-foot draft. Acoustic systems installed on board the PHIPPS and utilized during both Phases I and II were:

The Boomer System - consisted of an E G & G Uniboom sound source transducer and capacitance energy source, Raytheon receiving system and model PFR 196B dry paper 19" graphic recorder and an E G & G hydrophone streamer. The system was operated at a 300 watt=second level providing an acoustic signal of 0.4 millisecond duration with a frequency spectrum of 500 to 10,000 Hz.

The Side Scan System - was an E G & G Mark 1A side-scan sonar system which consisted of a dual-channel graphic recorder, a towfish and associated cables. This system transmits short 105 kHz bursts of sound in fanshaped beams which are 1° wide and 40° high to each side of the towed fish. The sound pulses, reflected from the bottom terrain, are received, processed, and continuously recorded graphically to display their lateral displacement from the towfish. As the vessel proceeds, a plan view of the area covered is produced on the chart. During this survey, the side scan sonar was operated on the scale which afforded a 500-foot search area to either side of the sonar transmitting a signal every 1/5 second. The recorder presents a graphic record 5 inches wide for each side and affords range resolution of 2 feet at the 500' scale of operation.

The Precision Echo Sounder - was a Raytheon (model DE-719) precision survey fathometer. This unit transmitted a 6° wide beam of a 200 kHz signal and afforded depth determination on the graphic recorder within ±0.25% of full-scale depth. The unit has controls to adjust motor speed, signal delay, and zero calibration to afford the accuracy in assumed standard sea water with a sound speed of 4800 feet per second.

Coring - The program was carried out from on board the M/V ATLANTIC TWIN, a 90' - long twin hulled motor vessel with a 28-foot beam and 6½-foot draft. The vessel was equipped with a hydraulic crane and was further modified to handle the Alpine "Vibracore". Grab sampling and bottom photography were accomplished from the M/V PHIPPS, in conjunction with the acoustic data collection.

The Alpine "Vibracore" is a bottom resting vibrating corer which utilizes a pneumatic impacting piston vibrator on top of a core pipe fitted with a 3½" I.D. plastic liner. The vibrator and core pipe are supported and guided by a vertical H-beam supported on the sea bed by 4 legs. The unit is 46 feet in height and is capable of obtaining a 40-foot core sample. The working weight of the unit is 4000 pounds and requires as much as a 30-ton pullout force toretract the 40-foot core from some sediment structures.

When driving the core pipe into the bottom, a point of refusal may be reached (or the core cutter may clog with the sample) and although further downward progress may be achieved, no additional sample enters the pipe. This limitation is overcome by a combination of vibration sampling and jetting. Here, vibration sampling is performed until refusal; at which time, the corer is returned to the surface, the partially filled core liner removed and a new one fitted. On the second run, a jet pump which is mounted on the guide is used to jet the corer to previous refusal depth, then jetting is shut down and vibrating done until either refusal or a full core is achieved. This process can be repeated as often as needed.

The Shipek Grab Sampler was used on the PHIPPS. Basically, this sampler is composed of two concentric half cylinders. The inner semicylinder, or sample bucket, is rotated at high torque by two helically wound springs. Upon contact with the bottom, it is automatically triggered by inertia. The sample bucket then rotates 180° and is held closed by residual spring pressure. The unit, equipped with the side closure, prevents washout.

The bottom photography was done under subcontract by Seatech, Inc., Rochester, N.Y., to obtain photographs of 16" x 24" areas of the sea floor at all grab sites, most core sites, and other selected areas.

The LORAC Type "B" Radiolocation System is a compact, solid state, low power hyperbolic system and was used for all position control on this program. The system is comprised of three base stations - one reference station and any number of mobile receiving stations.

LORAC base stations provide continuous wave (cw) signals such that the frequency separation between the center and green stations is a certain frequency and between center and red is another frequency. These heterodyne signals are phase compared with the constant phase reference signal to establish position information at the receiver.

Phase I Planning Procedures

This plan called for immediate mobilization of the LORAC navigation system with base stations at Rockport, Nahant, and Brant Rock (a reference station at Scituate). The PHIPPS was to be mobilized at Scituate with the LORAC receiver, boomer subbottom profiling system, side scan sonar, and precision echo sounder on board.

It was decided that a series of survey lines would be run one mile apart at approximately right angles to the shoreline throughout the assigned survey area. The survey area was from Cape Ann Light to Brant Rock, eastward to the 150-foot depth contour and generally inshore to the 40-foot depth contour, and was comprised of approximately 250 line miles.

All acoustic sensors were to be employed in the running of these survey lines. The side scan was to be operated on a 500 foot (each side) scale, thus affording 1/6 coverage on one mile spacing of survey lines.

A cross-tie line was run, generally north-south, across all these lines from Cape Ann to Brant Rock to provide continuity of information.

Phase II Planning Procedures

At the conclusion of Phase I of the Massachusetts' offshore sand and gravel inventory, an operating plan for the second Phase was generated. Elements of Phase II were to include vibratory coring, grab sampling, bottom photography, and continued acoustical surveying (subbottom profiling and side-scan sonar). Under the flexible framework of the overall program, efforts related to the various elements were to be balanced so that indications of potential sand and gravel deposits, emerging from Phase I, could be explored in the most efficient manner. The Phase I acoustical reconnaissance, previous knowledge of the area, and predetermined planning critieria formed the basis for generating the Phase II operating plan. The survey program was designed so that coring, grab sampling, and bottom photography would commence at the conclusion of the Phase I activity. The ATLANTIC TWIN, was committed solely to vibratory coring, while grab sampling and bottom photography were to be accomplished from the PHIPPS. Subsequently, the PHIPPS was to revert to acoustical surveying. Thus, the selection of bottom sampling and photographic sites was the first Phase II planning task to be addressed.

Bottom Sampling and Photographic Decisions

The purposes of bottom sampling was twofold: 1) to provide a physical interpretation of the acoustical records and 2) to permit assessment of the quality of sand and gravel deposits. It was recognized that coring would be more valuable in achieving such purposes than grab sampling because of the added dimension of depth. Grab sampling was therefore relegated to a supporting role. The role of bottom photography was to document sedimentary conditions and biologic activity at the sea floor.

In the early stages of the program, a series of criteria for selecting coring sites was developed by Raytheon and the Division of Mineral Resources. The criteria were consistent with the aforementioned purposes of bottom sampling. According to the guidelines, cores would be taken where:

Acoustical information and other sources of data indicated the possible presence of a significant sand and gravel deposit at or near the sea floor.

It was desired to delineate the boundaries of important deposits or to gain a better understanding of local marine geology.

Water depth was between 40 to 150 feet, the bottom was within Massachusetts territorial limits, and no active dumping was taking place. Sites deeper than 150 feet were considered unlikely to be commercially exploitable and were not studied.

A meeting between Raytheon and a representative of the Division of Mineral Resources was held on May 6 to delineate initial coring sites. Upon reviewing the Phase I acoustics it became apparent that sand and gravel zones were not readily identifiable, and initial coring efforts should be addressed to the identification of subbottom units. Several coring sites were then delineated in the southern section of the study area in accordance with the selection criteria. Sites were chosen in sedimentary basins which might contain sand and gravel, and at locations where a core would indicate both the identity of sedimentary fill and underlying basement material.

At subsequent meetings held May 8 and 9, 1972 the reconnaissance acoustical records from the entire study area were reviewed. A total of 40 core sites was established using a rationale based on the original selection criteria. Again, it was deemed necessary to collect samples before definite correlations between acoustics and subbottom units could be made.

Sixty-two sites for grab sampling were delineated during these meetings. Whereas subbottom profiles were of primary importance in planning coring operations, the side scan sonar records were relied upon heavily to select grab sites. This was because both the side scan sonar and the grabs provide information solely on the surface of the sea floor. An effort was made to distribute the grab sites throughout the entire study area and also to sample the various textural patterns present on side scan sonar records. A knowledge of surficial sediment composition was judged to be of considerable value in assessing the potential value of subbottom layers.

It was also decided at these meetings that the core and grab sites should also serve as locations for bottom photography. This was consistent with the documentary role assigned to photography in the program.

After the initial Phase II decision-making meetings, data from bottom sampling, photography, and subsequently, additional acoustics began to accumulate. This information served as a basis for frequency reassessment of the coring sites. Some new core sites were established where grab samples indicated the presence of "clean" sand and gravel, while others deleted where a high silt/clay content seemed probable.

The presence of at least four significant sand and gravel bodies was ascertained mid-way through the coring program. Subsequent coring was then oriented towards delineation of the boundaries of these deposits and to exploration of other areas having similar acoustical signatures.

Acoustic Survey Decisions

Acoustical surveying was scheduled to resume after the M/V PHIPPS had completed the grab sampling and bottom photography. The purpose of Phase II acoustic surveying was: 1) to more precisely delineate the geometry of potential sand and gravel deposits, and 2) to clarify geologic transition areas to gain a better understanding of local geologic history. Both the side scan sonar and subbottom profiling systems were to be employed again in Phase II.

By the time the grab sampling and photographic missions were completed, significant bottom sampling data had accumulated. A knowledge of the locations of major sand and gravel deposits and an understanding of offshore geology were developing. Indications grew that sand and gravel were present only as a surface skin in the southern end of the study area. However, significant deposits seemed to be located in the geologically - complex central region. Sandy surface sediments were widespread in the northern zone, but the sea floor sloped offshore abruptly in this area and the potential for commercial sand and gravel recovery seemed low.

On the basis of these indications, Phase II acoustic surveying was focused on the central portion of the study area. Uncertainty concerning the locations of major sand and gravel deposits in this region and incomplete exploratory bottom sampling precluded the limitation of "fine-grained" acoustical surveying to discrete areas. As a result, it was decided that reconnaissance track lines from line 16 to the low thirties should be filled in addtional parallel lines to achieve quarter-mile line spacing. This course of action was chosen to: 1) provide adequate coverage for delineating the geometry of suspected deposits, 2) insure coverage for deposits not yet discovered in the central region, and 3) generate side scan information for much of the sea floor in the area.

Coring

Coring operations were conducted from ATLANTIC TWIN carrying a crew of five. The ATLANTIC TWIN was selected as a platform for the Apline "Vibracore" on the basis of size, deck area, laboratory space, and stablility. The 40-foot corer was positioned along the starboard side of the boat with the base resting on deck at the stern and the top suspended from a gallows amidship. Core liners, winches, and air compressor were placed on the after deck. A laboratory used for analyzing cores was located just aft of the cabin on the weather desk. The LORAC navigation system receiving set was placed in the wheelhouse. The scientific party included a Raytheon geologist, a vibracore operator, a LORAC navigator, and a representative of the Division of Mineral Resources.

Several steps were involved in the collection of a core. The coring site which had been delineated during planning activities had to be located. This was accomplished with the use of the LORAC equipment, and the site was marked with a buoy. The corer requires a stable platform, so considerable effort was devoted to anchoring the boat. Anchors were set at the bow and stern of the ATLANTIC TWIN in positions such that wind and tidal currents would keep the boat at the coring site. During the anchoring procedure, the corer was prepared for operation. A new core liner and cutting edge were loaded into the barrel, the penetrometer was calibrated, and the air compressor was started.

Coring operations began when the boat was securely anchored and on station. The base of the corer was lifted over the side of the vessel with a hydraulic crane and lowered until it was suspended vertically from the amidship gallows. The corer was then slowly lowered until it came to rest on the sea floor. At this time, a final position was taken with the LORAC equipment.

Collection of the core itself was begun by starting the vibrator. Progress of the operation was monitored on the penetrometer by the corer operator, the Raytheon geologist, and the state representative. During the survey, an operating policy for the corer was developed. This policy may be summarized as follows:

> Vibration was discontinued after less than one additional foot had been penetrated in 3 to 4 minutes. Continuing longer might have caused the barrel to become stuck or damage the tip.

Vibration was abandoned after 30 to 35 feet of core penetration. Vibration frequently caused the contents of the corer to expand, and there was concern that the critical uppermost part of the core would be lost through the top.

If the corer fell over after 0 to 3 feet of penetration, a bedrock bottom was indicated and no further attempts were made.

In cases where a short core, brought on deck, seemed to contain sand and gravel, an attempt for increased penetration was made. This was accomplished either by jetting to the depth previously obtained, and then vibrating, or again vibrating down from the surface.

Attempts for greater penetration were not made if sand and gravel failed to be obtained on the first try. The success ratio for repeated attempts was low, as was the likelihood of subsurface sand and gravel being of economic value.

After a core had been collected, the corer was raised to its original position on deck. The core liner was extended, sawed into 5 to 10 foot sections, capped, and labeled. The sections were then brought into the core laboratory for analysis.

In the laboratory each section was laid in a wooden trough and a longitudinal strip, 1 to $1\frac{1}{2}$ inches wide, was cut out of the liners. The contents were then examined, described, and sampled. Principal elements of the description were sediment texture, color, thickness of layers, and any outstanding characteristics such as hardness, reduced zones, or heavy minerals. Sampling was carried out so that economically-promising deposits could be further described by subsequent laboratory analysis. Samples were therefore collected principally from layers of sand and gravel which were substantial in thickness. In some cases, layers containing a mixture of sand and gravel with finer sediments (silt and clay) were sampled with the thought that they might be of marginal economic value.

After the cores had been described, the longitudinal strips were replaced and taped. The cores were sealed, relabeled, and stored. As the core examination proceeded, the ATLANTIC TWIN would retrieve anchors and steam for the next coring site.

Coring operations began on May 7 and terminated on May 24. During this period, 45 coring sites were occupied. Operations had to be suspended after four days, principally because of weather. On operating days, cores were retrieved from an average of 3.2 and a maximum of five sites. Coring was conducted during daylight hours for an average of 12 hours a day.

Acoustic Operations

All acoustic operations were conducted on board the M/V PHIPPS. The prime area of interest (in the center of the assigned survey area) was surveyed at $\frac{1}{4}$ mile spacing running parallel to lines completed during Phase I. Some 500-line miles of survey was conducted during the period of this contract.

The boomer system continued to perform well. The receiver was adjusted to observe depth to bedrock, as required in the original specifications, meanwhile developing the stratifications present near the sea floor. The acquired subbottom records provided excellent subbottom descriptions with depth measurement to bedrock or compacted till as deep as 250 feet below the sea floor.

The side scan sonar developed records with marked contrast between various areas of differing sediment characteristics on the bottom. The patterns observed on the graphic records were highly indicative of the sediment characteristics and correlated with bottom photos and samplings.

The DE-719 precision fathometer was also operated on the PHIPPS during all acoustic survey lines. The records from its operation were not processed but submitted to the Commonwealth as a data bank. These records provide depth measurements which, when corrected for a 6-foot draft and the state of the tide, will afford measurement of precise bathymetry to within $\pm$ 1/2 foot.

Bottom Photography

Bottom photography afforded an opportunity to positively identify the surficial sediments of the sea floor. Photographs were acquired at all but five of the grab sample sites, at 24 core sample sites and at 18 other stations, for a total of 103 bottom photographs distributed throughout the survey area.

Shipek Sediment Sampler

The Shipek Sediment Sampler, operated from on board the PHIPPS, gave continuously reliable service. At numerous sites the samples were small or nonexistent but this was due to the rocky or cobbly bottom; verified in bottom photos.

Isopach Map Development

The development of the isopach map which presents areas of equal geology unit thickness, commenced with a thorough examination of the acoustic records in the areas where coring had shown sand and/or gravel. The records were initially examined to ascertain if the sand and gravel occurred consistently in similar morphologic deposits or environments. Examination of the cores and the acoustic records further suggested that the sand and gravel occurred not as separate and distinct deposits, but generally in an heterogeneous accumulation which commonly had irregular boundaries. Thus, the occurrence of sand and gravel has been mapped as a single unit for presentation in this report.

One other general aspect of this analysis should be pointed out. Specifically, the Holocene reworking of previously deposited offshore tills has procuded a thin veneer of sand, gravel, and cobbles over much of the ocean bottom, particularly south of Boston Harbor. This areally extensive veneer, generally less than $2\frac{1}{2}$ feet thick at any point, made it particularly difficult to determine a "zero-thickness" at the perimeter of sand and gravel accumulations. The dotted lines represent a proforma boundary to allow assessment of the local deposits' volumetric contact. Several of these deposits, expecially those in the souther half of the survey area, may be interconnected by a veneer of sand and gravel crossing the outcrops of bedrock and/or till which generally bound the sand and gravel accumulations.

Following the initial examination of the acoustic records for general characteristics, the subbottom profiles were re-examined in detail and mylar overlays of both known and potential sand and gravel deposits were constructed. These records were also marked for occurrence of sea floor bedrock and for till outcrops as the location of sand and gravel deposits, sampled by coring, demonstrated a high correlation with proximity to these outcrops.

The lineal occurrence of sand and gravel, together with bedrock and/or till outcrops occurring in the individual acoustic track line records, were then transferred to a base map from which preliminary areal distributions were derived. As the initial analysis alone indicated that the sand and gravel bodies were both of limited areal extent and irregular in outline, the decision was made to double the base map scale in the central portion of the survey area.

The sand and gravel bodies originally plotted on the initial base map were then rechecked and transferred to the expanded scale central area plotting sheet. Concurrently, both sand and gravel thicknesses and water depths for data points at a nominal 600 foot spacing, plus all maxima and minima points, were recorded in the large scale map. At each core location thickness, measurements were again cross checked. As in the previous small scale map the distribution of bedrock and/or till exposed, together with the measured water depth at the same 600-foot interval, was also recorded.

The final step in the generation of the maps involved establishment of the contour lines indicating deposit thicknesses. These lines, which enclose all areas having a depth equal to or greater than the indicated thickness, are of equal depth or isopachs.

To provide a measure of data confidence which is directly correlative with acquisition sampling density of both acoustic and physical samples, a consistent notation was adopted:

Those deposits, which were selected based only on their acoustic profile characteristics and which occurred on two or less traverses, are indicated with closed geometric shapes.

Those deposits which were sampled in more than two traverses and which had only limited physical sampling to substantiate their occurrence and extent, are indicated with an irregular dotted line approximating the deposit boundary. While it was also desirable to achieve a closed form for these deposits, one potential accumulation of sand and gravel is presented which is open to seaward where its offshore extent could not be ascertained. It extended beyond the geographical limits of this survey. Those deposits crossed by a series of parallel acoustic traverses and which were sampled at multiple core stations have the areal extent and the thicknesses represented by closed contours. Consistent with the adopted notation, the maximum areal extent of "zero thickness" of these latter deposits is similarly indicated with a closed dotted boundary. As discussed, an exact determination cannot be made in the presence of the veneer of sand and gravel which covers the surface of much of the area south of latitude 42^{o} 26' N. A contour interval of three feet as specified has been employed except for the central portion of area I where deposit thicknesses made a 6-foot interval necessary to preserve presentation quality.

Surficial Sediment Map

One of the principal intents of the Massachusetts sand and gravel inventory was to develop a map of surficial sediments on the sea floor. This was accomplished using the side scan sonar records, coring data, grab results, and bottom photographs. The first step in generating the map involved the examination of the side scan records and cataloging the various textural patterns encountered. Several patterns occurred which could be differentiated from each other. The distribution of these patterns along the track lines was marked on a base map. The types of bottom materials encountered at the tops of cores, in grab samples, and depicted in bottom photographs were noted at each sampling and photographic site. This enabled the correlation of side scan patterns with bottom sediment types. Six different bottom types could be recognized in the study area: 1) boulders or bedrock with patches of coarse sediment, 2) cobbles with sand and gravel, 3) sand and gravel, 4) sand, 5) silty sand, and 6) a heterogenous mixture of sediments ranging from cobbles to silt or clay. Silt and clay were also occasionally found with types 1, 3, and 4. The final step in creating the map involved drawing in boundaries of the bottom types by referring to the distribution of side scan sonar patterns.

The positions of sand and gravel deposits (as shown on the isopach map) bears a reasonably close, but not perfect, resemblance to the surficial sediment map. This apparent disagreement does not mean that either of the maps is in error. The isopach map is derived from subbottom profiling records on which the uppermost few feet of the bottom are difficult to resolve. The surficial sediment maps are based on side scan records, samples, and photographs which show only the materials exposed on the sea floor. Examination of the core descriptions frequently indicates that surface sediments represent only a thin "skin" superimposed on deposits of a different composition.

A noteworthy phenomenon observed during preparation of the surficial sediment map is that both the corer and the grab sampler tends to sample bottom materials selectively. At many sites, numerous cobbles appearing in photographs were not retained in corresponding grabs or cores. This undoubtedly reflects the fact that cobbles are similar in size to the core barrel or open grab sampler. When the samples were being collected, these larger particles tended to be pushed aside. Thus, the photographs provide the most accurate indication of the appearance of the sea floor.

RESULTS

Marine Geology

The acoustic and bottom sampling data generated by the sand and gravel inventory can be used to evaluate the marine geology of the nearshore region in Massachusetts Bay. While the principal purpose of the inventory was to investigate the characteristics of sand and gravel deposits, the distribution of other types of sediments and geologic formations was ascertained. An understanding of the overall geologic composition of the study area is valuable from an academic standpoint and can also be used to gain further insight into the sand and gravel bodies.

The principal types of geologic units which occur in the study area and their probable origin can be described as follows:

Bedrock consists of crystalline Pre-Cambrian and Paleozoic formations in the northern and southern portions of the study area and Paleozoic sedimentary rocks in the region off Boston Harbor. Bedrock crops out frequently offshore, particularly in the northern and southern sections. Its composition is extrapolated from onshore geology and the acoustic signature.

During the Pleistocene, continental glaciers advanced through the region at least twice, extending to and possibly beyond the Cape Cod-Georges Bank area. A heterogenous deposit of boulders, gravel, sand, silt, and clay categorized as glacial till was laid down beneath the glacier as a ground moraine. The ground moraine had a hummocky surface and did not completely cover the pre-existing bedrock. Separate episodes of glacial advance caused at least two till units to be superimposed on each other in some regions. At the present time, till occurs in the southern and particularly in the central parts of the study area.

The nearshore portion of Massachusetts Bay underwent two cycles of valley cutting and filling during the Pleistocene. A series of large valleys up to 3500 yards wide and 300 feet below present-day sea level were cut into the unconsolidated till. These were either cut by rivers issuing from the glacier during an episode of retreat or by the scouring action of the ice as the glacier advanced. The axis of these valleys as depressions was northwest-southeast. Subsequently, the region was submerged beneath the ocean and the former valleys were filled with interbedded glaciomarine silts and clays. Emergence then took place and the filled valleys were partially re-excavated during a period of less intense subaerial erosion. Another submergence led to a deposition of more uniform glaciomarine silty clays in the second generation of valleys. Because these periods of glaciomarine deposition occurred during interglacial periods, they are partially covered by a layer of till laid down as the glacier re-occupied the area.

After (or possibly concurrent with) the final retreat of the glacier from Massachusetts Bay, the region was submerged beneath the sea. A new cycle of glaciomarine silty clay deposition occurred and depressions in the sea floor were filled with this uniform sediment. This submergence was followed by temporary emergence cause by isostatic rebound of the earth's crust. It is generally recognized by geologists that the sea fell approximately 70 feet below the present level. Till in the central and southern portions of the study area was reworked by shoreline and nearshore processes, resulting in the deposition of nearshore marine sand and gravel. The sand and gravel was laid down in thin, areally extensive, sheets located 70 to 100 feet below present sea level. These deposits will be discussed in depth in the text.

The rise of sea level to its present position has subjected nearshore Massachusetts Bay to continuing marine reworking. This caused the previously more continuous sand and gravel sheets to become separated and irregular in configuration. The reworking has also distributed a surface "skin" of reworked marine sand and gravel over much of the central and southern portions of the study area.

Subaerial erosion and wave attack on land have been contributing sediments offshore since sea level rose to its present position. In the northern portion of the study area a continuous sheet of nearshore marine silty sand has extended outward from the coast. Marine silts and clays, largely organic in composition, are being contributed to inshore parts of the central study area from Boston Harbor. This influx of modern fine sedimentation is exaggerated by dumping practices.

In summary, eight geologic units can be recognized in the nearshore region of Massachusetts Bay. These are listed as follows:

Geologic Age	Unit
Holocene	Marine silts and clays
Holocene	Nearshore marine silty sand
Holocene	Reworked marine sand and gravel
Holocene	Nearshore marine sand and gravel
Pleistocene	Glaciomarine silty clay
Pleistocene	Glaciomarine silts and clays
Pleistocene	Glacial till
Pre-Cambrian, Paleozoic	crystalline and sedimentary bedrock

The regional marine geology of nearshore Massachusetts Bay is illustrated by six acoustical cross-sections shown in the Appendix. These cross-sections represent east-west subbottom profiling lines 8, 15, 21, 26, 34, and 41, which were chosen because they typify the geology of the northern, central and southern portions of the study area. In constructing the cross-sections, subsurface acoustical reflectors have been traced and multiple reflections were omitted. The results show geologic units below the sea floor in a more readily-interpreted format than the original records.

The typical cross-sections may be discussed as follows:

Line 8 - The bedrock which is so prevalent in the southern part of the study area crops out along much of this transect. The most extensive outcrop extends from 1817.5 to 1753.7. Depressions in the bedrock surface are filled with glacial till. A thin veneer of sand and gravel covers both bedrock and till at the sea floor.

Line 15 - Irregularities on the bottom are caused by outcroppings of bedrock and possibly till. Two episodes of glaciomarine silty clay deposition have filled the depression between 0821 and 0827. Coarse sediment on the sea floor has resulted from reworking of glacial till.

Line 12 - The most prominent feature along this transect is the large system of depressions at the outer end filled with glaciomarine sediment. It can be seen that the lowest fill deposit has been truncated, apparently by subaerial erosion. These former stream valleys were in turn buried by sedimentation. Either bedrock or till crops out at the sea floor along much of the shoreward end. Fine sand resulting from marine reworking of glacial deposits extends to a depth of several feet over the sediment filled basins. Elsewhere, a thin veneer of coarser reworked sediment partially covers the surface.

Line 26 - Several sediment-filled depressions are interspersed with out-crops of bedrock or, more probably, till. The outermost depression is filled with interbedded glaciomarine silts and clays. The depression between 1251 and 1306 appears to contain glaciomarine silty clay overlying glacial till. Both reworked coarse sediment and fine sand contributed from shore-based sources compose the surficial veneer.

Line 34 - The irregular surface of the strong basement reflector which crops out occasionally suggests that it is crystalline bedrock reappearing in the northern portion of the study area. Depressions in the bedrock are filled with fine glaciomarine sediment. A thin sheet of silty sand has prograded out from the modern shoreline and covered most of the sea floor.

Line 41 - This line is short because the bottom slopes steeply offshore. Crystalline bedrock crops out near shore and then has been eroded to create two depressions which contain fine glaciomarine deposits. Modern silty sand blankets the glaciomarine material.

Existing Economic Deposits

The reconnaissance survey and subsequent analysis has resulted in the identification of fifteen areas of potentially economic sand and gravel which are identified in the Appendix by roman numerals. These numbers indicate an approximate economic ordering based upon volumetric extent, aggregate composition, and general logistic considerations.

Numbering is not intended to be a final ranking as many other factors must be considered in arriving at this decision. Additionally, there is the very real need to do extensive local development coring and additional acoustic profiling to definitively ascertain each deposit's economic value. For presentation, deposits have been divided into three groups based primarily upon the amount of deposit possible using the available acoustical and physical data.

Five deposits have been identified which contain appreciable quantities of aggregate. These deposits have been determined based upon their occurrence on several parallel acoustic profiling tracklines and multiple core site samplings within each deposit. These accumulations have individual areal extents which may approach fifteen million (15×10^6) square yards and local thicknesses in excess of 30 feet.

The second series of seven deposits have been identified based on acoustic characteristics and similarity to those deposits substantiated by physical (core) samples. These accumulations, like the five major deposits, are indicated by dashed lines enclosing irregular shaped bodies. The areal extent of these latter deposits is generally slightly smaller than those of the first category. Maximum area, however, approaches eight million (8×10^6) square yards. As there were no cores taken in this series of deposits, it was not deemed advisable to attempt thickness and volumetric determinations. However, based upon the acoustic profiles acquired, thicknesses of these deposits do not exceed twenty feet.

The last series of three potential deposits is indicated by closed geometric shapes. While the existence of sand and gravel in these areas is uncertain, geographic areas have been indicated. As a class, these deposits are characteristically smaller in areal extent averaging two million (2×10^6) square yards and appear to be much thinner (i.e., less than fifteen feet).

Geographically, all the identified deposits except one are located in the area directly seaward of Boston Harbor essentially lying between the 10 and 20 fathom depth contours. Significantly, twelve of the fifteen identified potential deposits of sand and gravel occur between latitudes 42° 17' N and 42° 27' N.

A word of caution must be injected at this point as, in almost all cases, these assessments are based on a very limited number of cores from each individual area. Caution must also be exercised in extending the areal extent of these deposits which generally are less than six feet thick over extensive areas. This is especially true in the offshore Boston Harbor area where recurrent glaciation and till deposition have been followed by multiple stands of sea level allowing substantial reworking and redistrubtion of deposited sediments. The factors must be remembered in examining the potential deposits presented in the appendix. Additional coring and profiling is essential to accurately delineate the described deposits.

Within the first class of five deposits, care must be used in evaluating areas III, IV, and V. Specifically, though both cores and the acoustic records indicate thicknesses in excess of twelve feet, these deposits are essentially local concentrations of the more extensive veneer covering much of the southern portions of the study area. Additionally, while individual layers can be tracked outward from the core sites, the complex glaciomarine deposition history of these nearshore areas provide substantial reason to suspect lateral grading within the identified units. Thus, there is a strong requirement for more detailed acoustical and physical sampling to define those potential deposits identified in this reconnaissance survey.

The five primary areas of potential sand and gravel occurrence presented in the Appendix are discussed below:

I. (30.5 MM yds^3) - The deposit, which trends generally NW-S, is approximately 4500 yards long by 1500 yards wide, and has an average depth of 14 feet. It is the second largest deposit of sand and gravel identified during the investigation and is centered at 42° 22' N, 70° 47' W. Based on the core data, surface sediments within the irregularly shaped boundary consist primarily of sandy gravel which extend to depths in excess of 30 feet. Within the deposit, a layer of medium sand up to three feet in thickness may locally cover the sandy gravel accumulations. As displayed, two subareas having sandy gravel in excess of 15 feet, occur one in the north-central and the second in the southern portion of this deposit. The deposit itself appears to sit above the level of the general bathymetry and may represent a residual glacial feature. Cores 34 and 39 are from within this deposit.

II. (27.3 MM yds^3) - This deposit, which trends more WNW-ESE, is approximately 6500 yards long by 1500 yards wide and has an average depth of 8 feet. It is centered at 42° 18' N, 70° 43' W. Based on the five cores (numbers 14, 15, 32, 36, and 37) which sampled this deposit, the material of this second surface deposit consists principally of gravelly sands which reach thicknesses of 20.5 feet. Over portions of the area, however, the gravelly sands are covered by a two to three foot thick veneer of fine to medium sand. Both the overlying sand and the underlying gravelly sand have been mapped as one unit. Additionally, there are four places within the confines of this deposit where sea floor outcrops of till and/or bedrock occur. These are depicted as hatchered areas.

III. (10.6 MM yds^3) - The third area which appears to contain a significant accumulation of aggregate is a very irregular shaped deposit, again of general NW-SE orientation. Its rough dimensions are 6000 yards long by 1200 yards wide and has an average depth of roughly 4 feet. The deposit is centered at 42° 24' N, 70° 47' N. Four cores (numbers 24, 27, 28, and 45) were taken within the boundary of this deposit. The cores from area III sampled the greatest variability of sediment within any one deposit being primarily sandy gravel and sands in the north and apparently grading into finer material; fine to medium sands in deeper water. This is particularly evident in the lobate feature which forms the southeastern portion of this deposit.

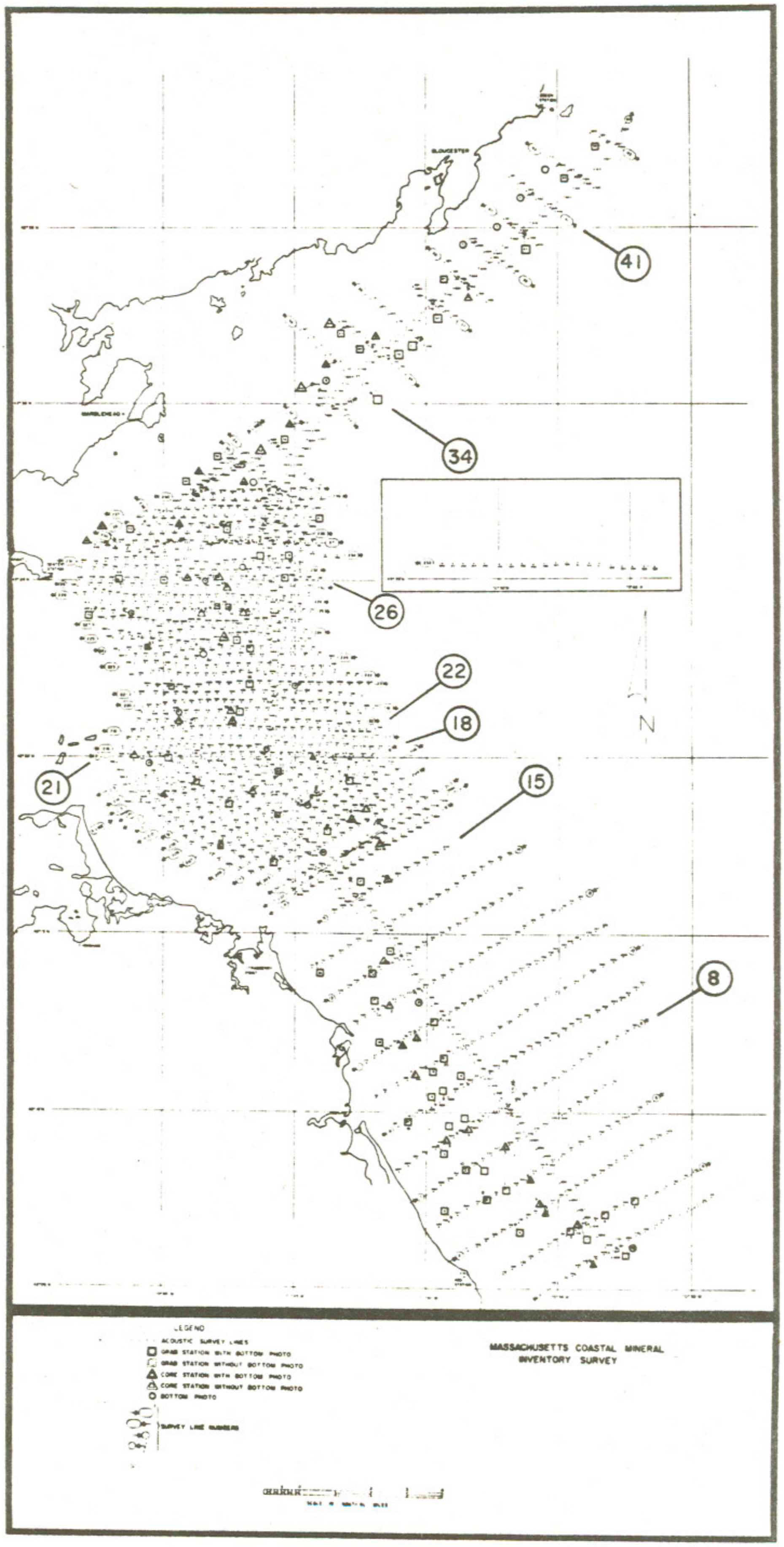
Acoustic records from this area maintain the general characteristics of the deposit farther north, however, core number 27 from within this sub-feature indicates a fine sand overlying silts and clays. As the deposit is bounded by numerous sea floor outcrops of bedrock and till, these features probably both control its areal expression and ha e contributed the sediments respectively. It should also be noted that this deposit does not anywhere attain even moderate thicknesses and probably should be considered more as an area of local thickening of the extensive sand and gravel veneer previously discussed.

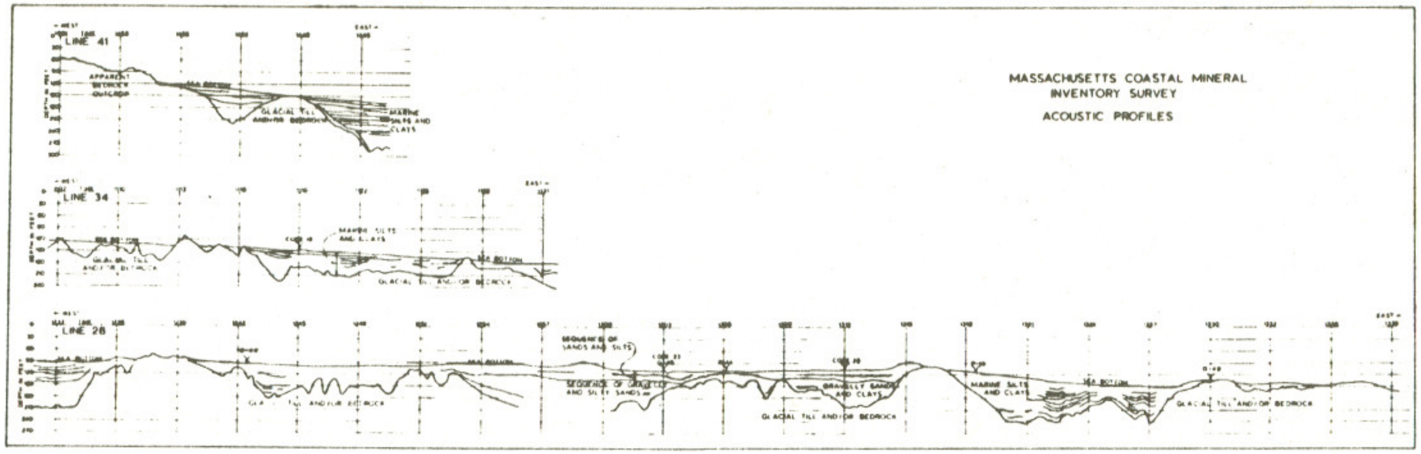
IV. (35.2 MM yds^3) - The fourth deposit which maintains the NW-SE orientation of the previous deposits is approximately 7000 yards long by 2400 yards wide and has an average thickness of 7 feet. This deposit which is centered at 42° 07.5' N., 70° 34' W. contains the largest computed quantity of potential aggregate. Within the deposit bounds, three cores (numbers 1, 2, and 4) were obtained. As in area III, a rather high degree of variability was observed in these samples which were all situated along the southwestern perimeter of the deposit. The areal extent has been determined primarily by acoustic records and the possibility thus exists that while the individual layers can be traced throughout the deposit, sediments may grade into finer material to seaward.

The cores indicated sandy gravel in the thicker central area with gravelly sands occurring at both the NW and SE extremities. Core #2 also indicated a four foot thick zone of fine-to-medium sand overlying the central area sandy gravels. Maximum thicknesses measured from the acoustic records locally reach fifteen feet with the sand, gravelly sand, and sandy gravel all plotted as a single unit.

V. (11.1 MM yds^3) - The last of the five major areas of potential sand and gravel reserves is centered as 42° 18', 70° 49' W. Again displaying the general NW-SE orientation of the majority of the identifiable areas, the deposit is roughtly 4500 yards long by 1400 yards wide and 4½ to 5 feet in average thickness. The deposit itself is very similar to III. The acoustic profiles show a hummocky underlying surface of till covered bedrock with a large outcrop occurring on the sea floor in the north central portion of this deposit. For this reason and because the one core (number 2) indicated only 3 to 3½ feet of gravelly sand underlying an eighteen inch thick fine sand veneer, the deposit is considered marginal. The deposit has been included, as one of the first class of five, primarily based upon the acoustic records which indicate increased thickness of the gravelly sand member to the south and southeast of the core location.

APPENDIX


GLOUCESTER
MARBLEHEAD
41
34
26
22
18
21
15
8
N
LEGEND
ACOUSTIC SURVEY LINES
GRAB STATION WITH BOTTOM PHOTO
GRAB STATION WITHOUT BOTTOM PHOTO
CORE STATION WITH BOTTOM PHOTO
CORE STATION WITHOUT BOTTOM PHOTO
BOTTOM PHOTO
SURVEY LINE NUMBERS
MASSACHUSETTS COASTAL MINERAL
INVENTORY SURVEY


MASSACHUSETTS COASTAL MINERAL
INVENTORY SURVEY
ACOUSTIC PROFILES
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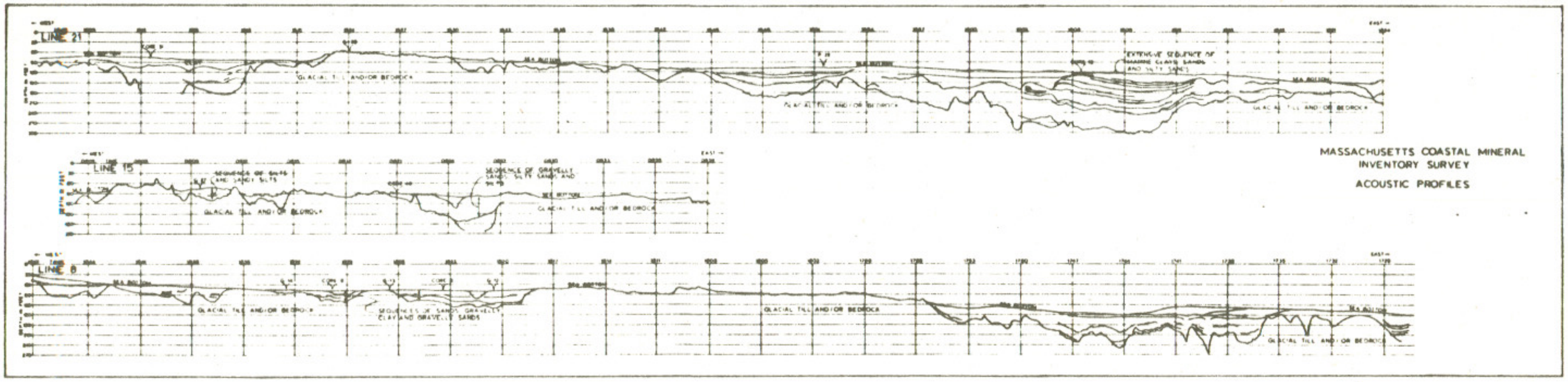
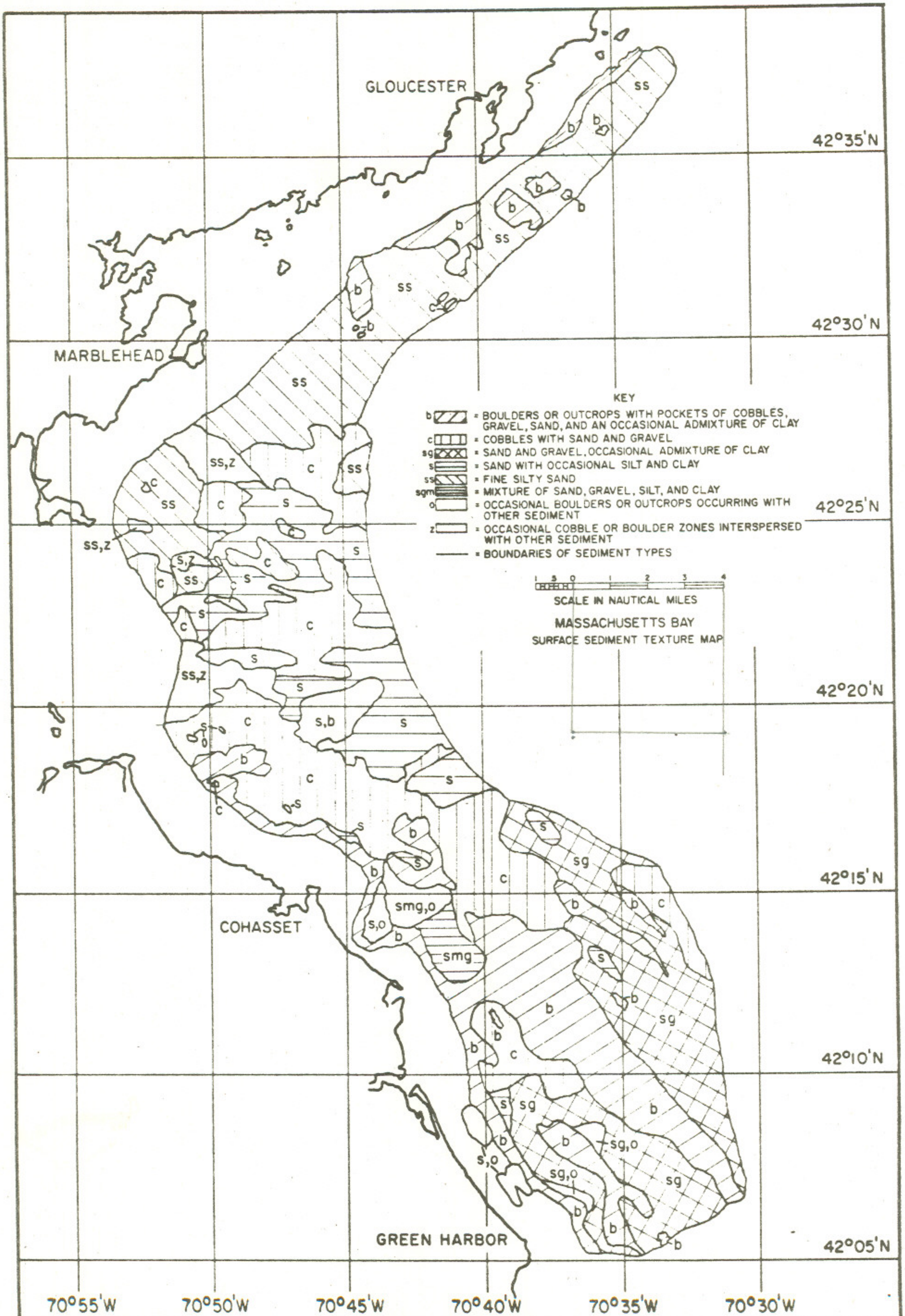
APPARENT BEDROCK OUTCROP
SEA BOTTOM
GLACIAL TILL AND/OR BEDROCK
MARINE SILTS AND CLAYS
LINE 34
MARINE SILTS AND CLAYS
SEA BOTTOM
GLACIAL TILL AND/OR BEDROCK
LINE 28
SEA BOTTOM
SEQUENCES OF SANDS AND SILTS
SEQUENCE OF GRAVELLY AND SILTY SANDS
GRAVELLY SANDS AND CLAYS
MARINE SILTS AND CLAYS
GLACIAL TILL AND/OR BEDROCK


MASSACHUSETTS COASTAL MINERAL
INVENTORY SURVEY
ACOUSTIC PROFILES
LINE 21
GLACIAL TILL AND/OR BEDROCK
SEA BOTTOM
EXTENSIVE SEQUENCE OF MARINE CLAYS, SANDS AND SILTY SANDS
LINE 15
SEQUENCE OF GRAVELLY SANDS, SILTY SANDS AND SILTS
SEA BOTTOM
GLACIAL TILL AND/OR BEDROCK
LINE 8
SEA BOTTOM
GLACIAL TILL AND/OR BEDROCK
SEQUENCES OF SANDS, GRAVELLY CLAY AND GRAVELLY SANDS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MARBLEHEAD
COHASSET
GREEN HARBOR
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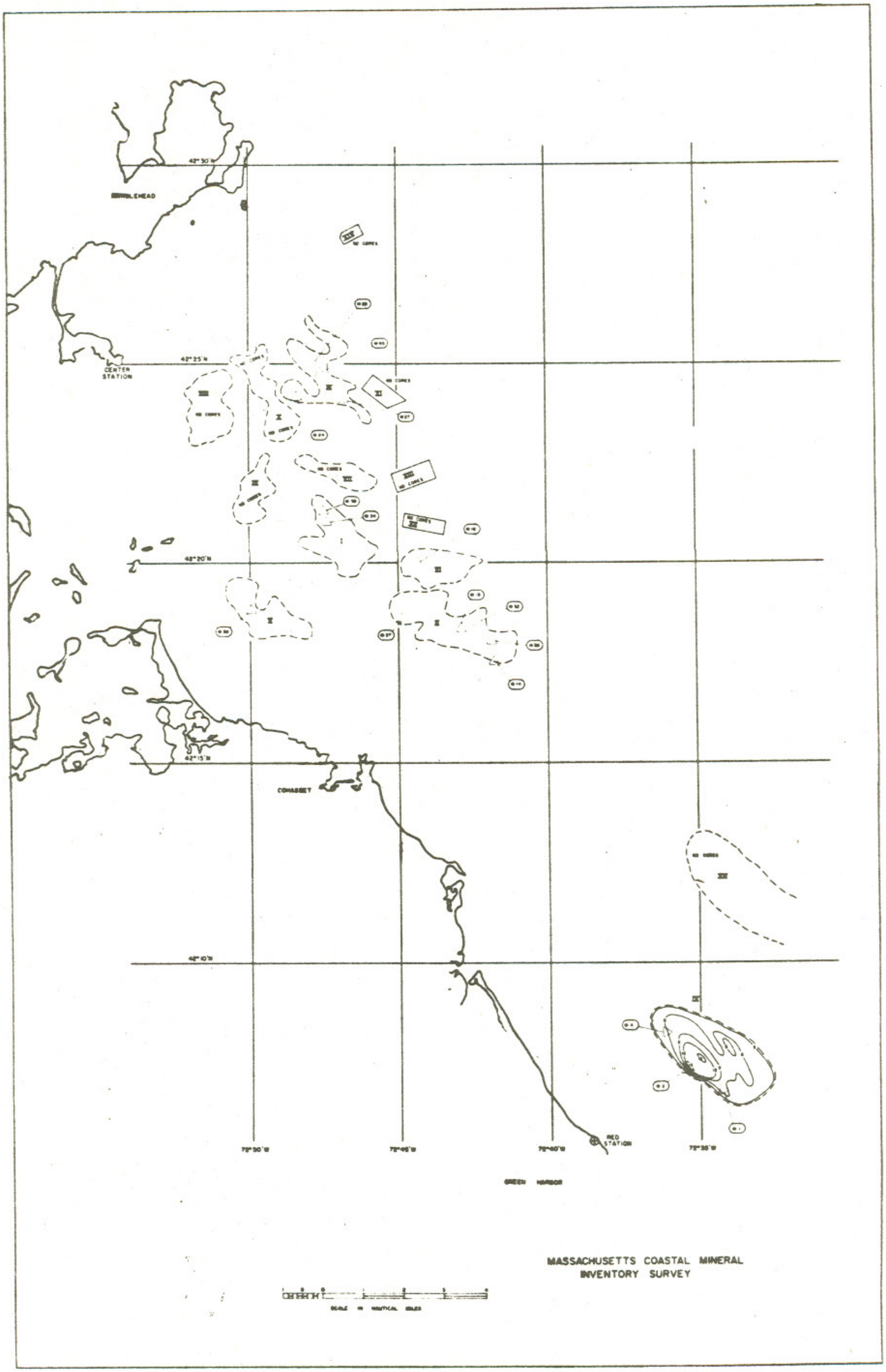
42°20'N
42°15'N
42°10'N
42°05'N
70°55'W
70°50'W
70°45'W
70°40'W
70°35'W
70°30'W
KEY
b = BOULDERS OR OUTCROPS WITH POCKETS OF COBBLES, GRAVEL, SAND, AND AN OCCASIONAL ADMIXTURE OF CLAY
c = COBBLES WITH SAND AND GRAVEL
sg = SAND AND GRAVEL, OCCASIONAL ADMIXTURE OF CLAY
s = SAND WITH OCCASIONAL SILT AND CLAY
ss = FINE SILTY SAND
sgm = MIXTURE OF SAND, GRAVEL, SILT, AND CLAY
o = OCCASIONAL BOULDERS OR OUTCROPS OCCURRING WITH OTHER SEDIMENT
z = OCCASIONAL COBBLE OR BOULDER ZONES INTERSPERSED WITH OTHER SEDIMENT
= BOUNDARIES OF SEDIMENT TYPES
SCALE IN NAUTICAL MILES
MASSACHUSETTS BAY
SURFACE SEDIMENT TEXTURE MAP

1.3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CENTER STATION
42°20'N
42°15'N
COHASSET
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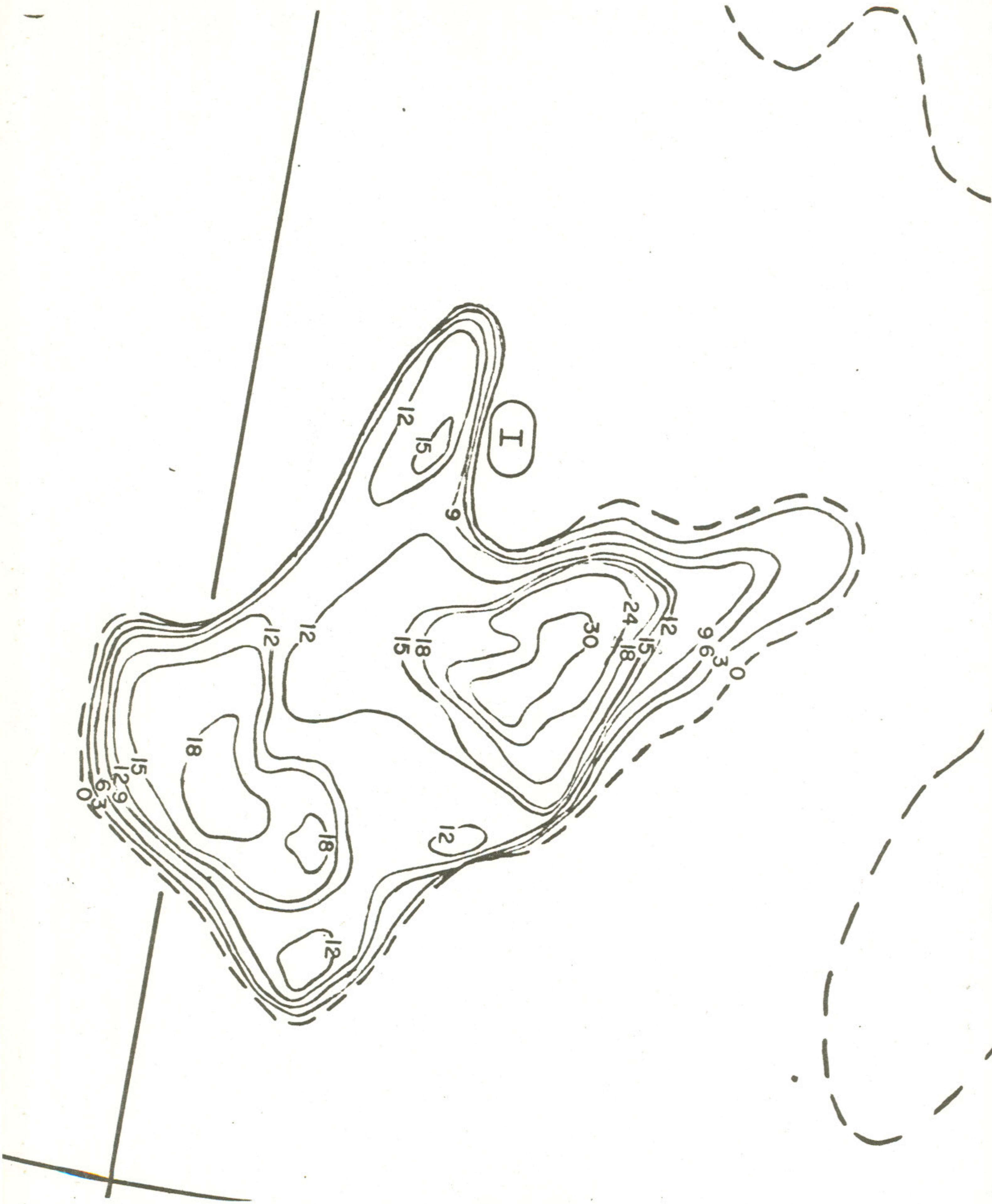
RED STATION
GREEN HARBOR
NO CORES
MASSACHUSETTS COASTAL MINERAL INVENTORY SURVEY
SCALE IN NAUTICAL MILES



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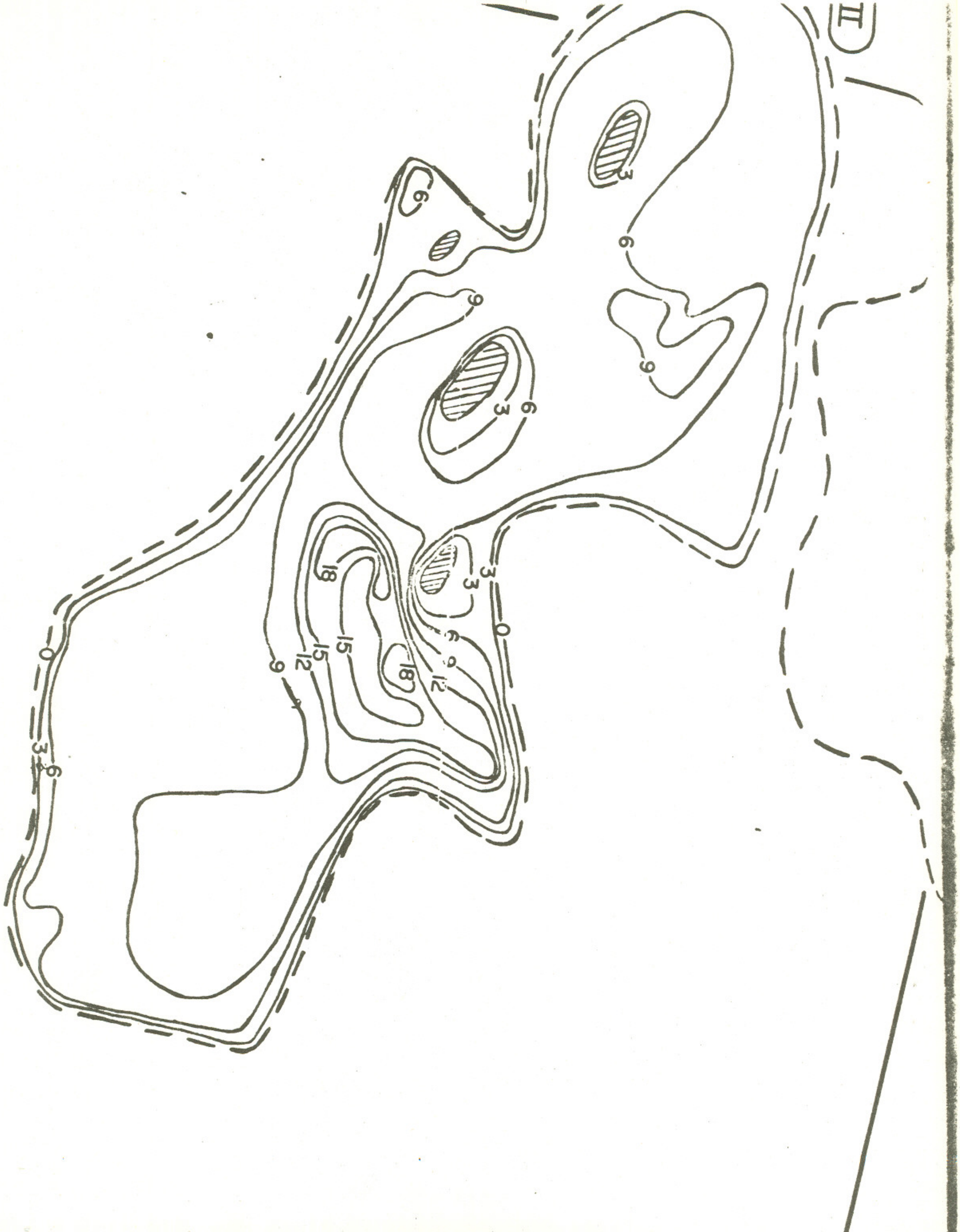
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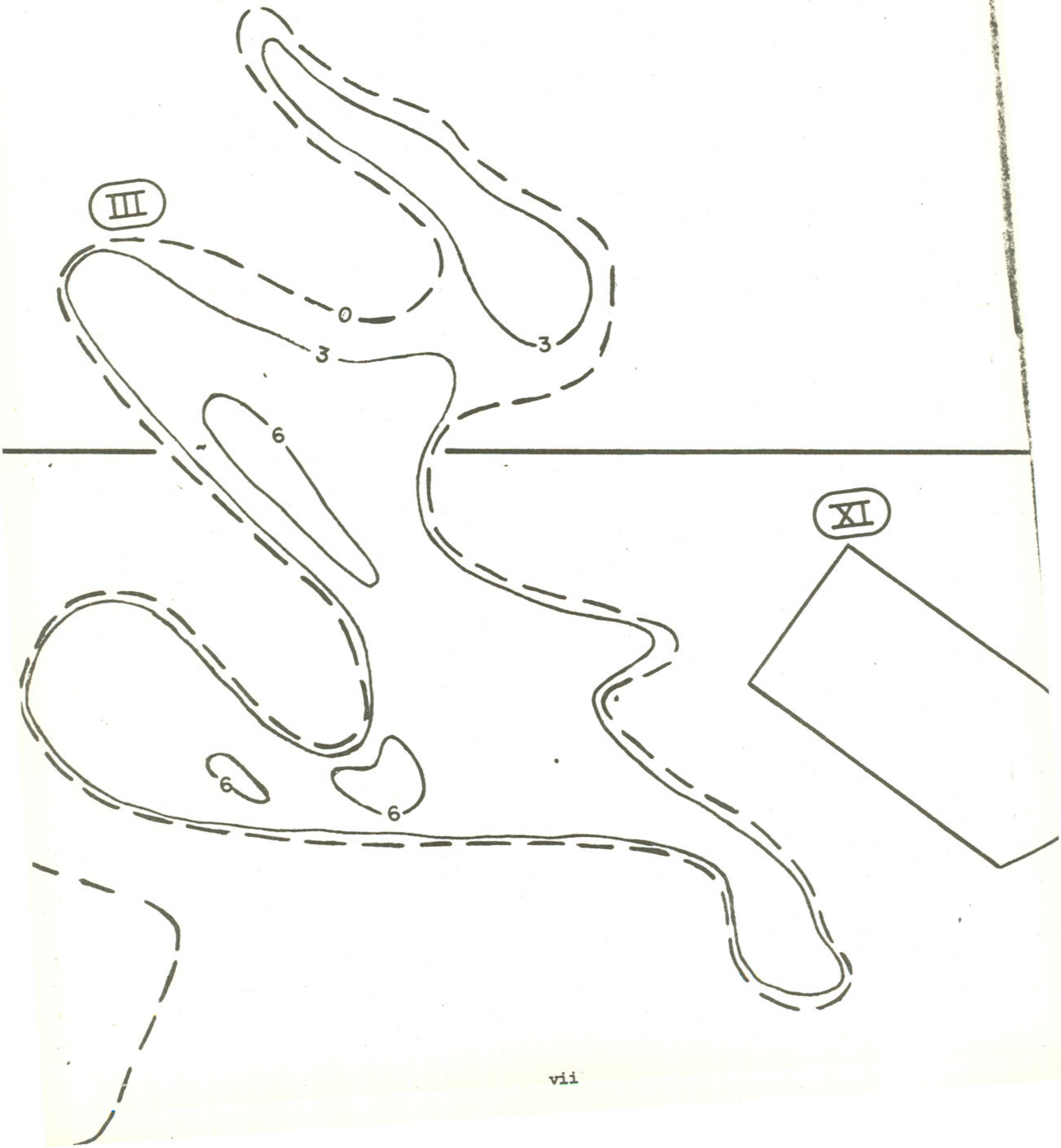
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XI
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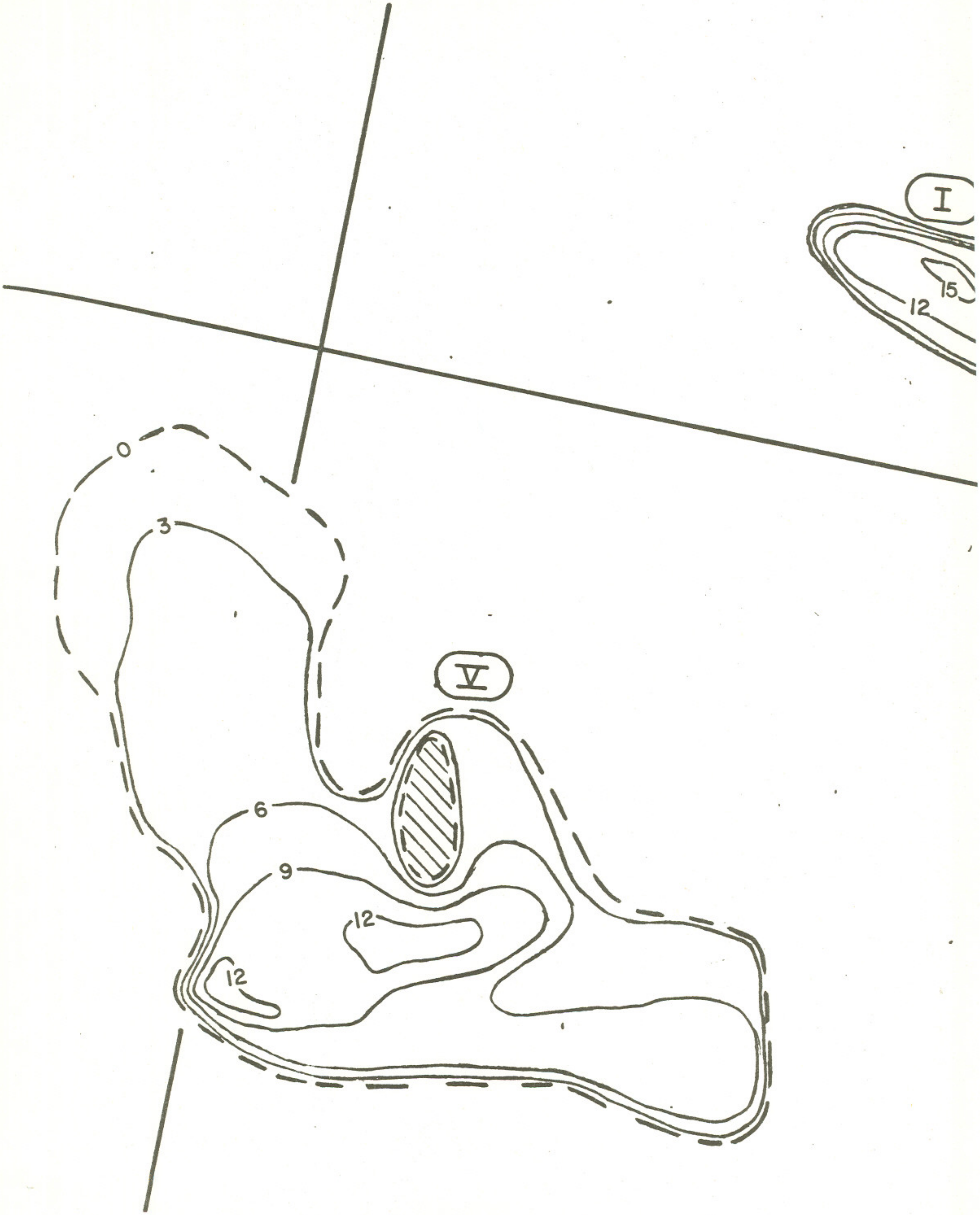
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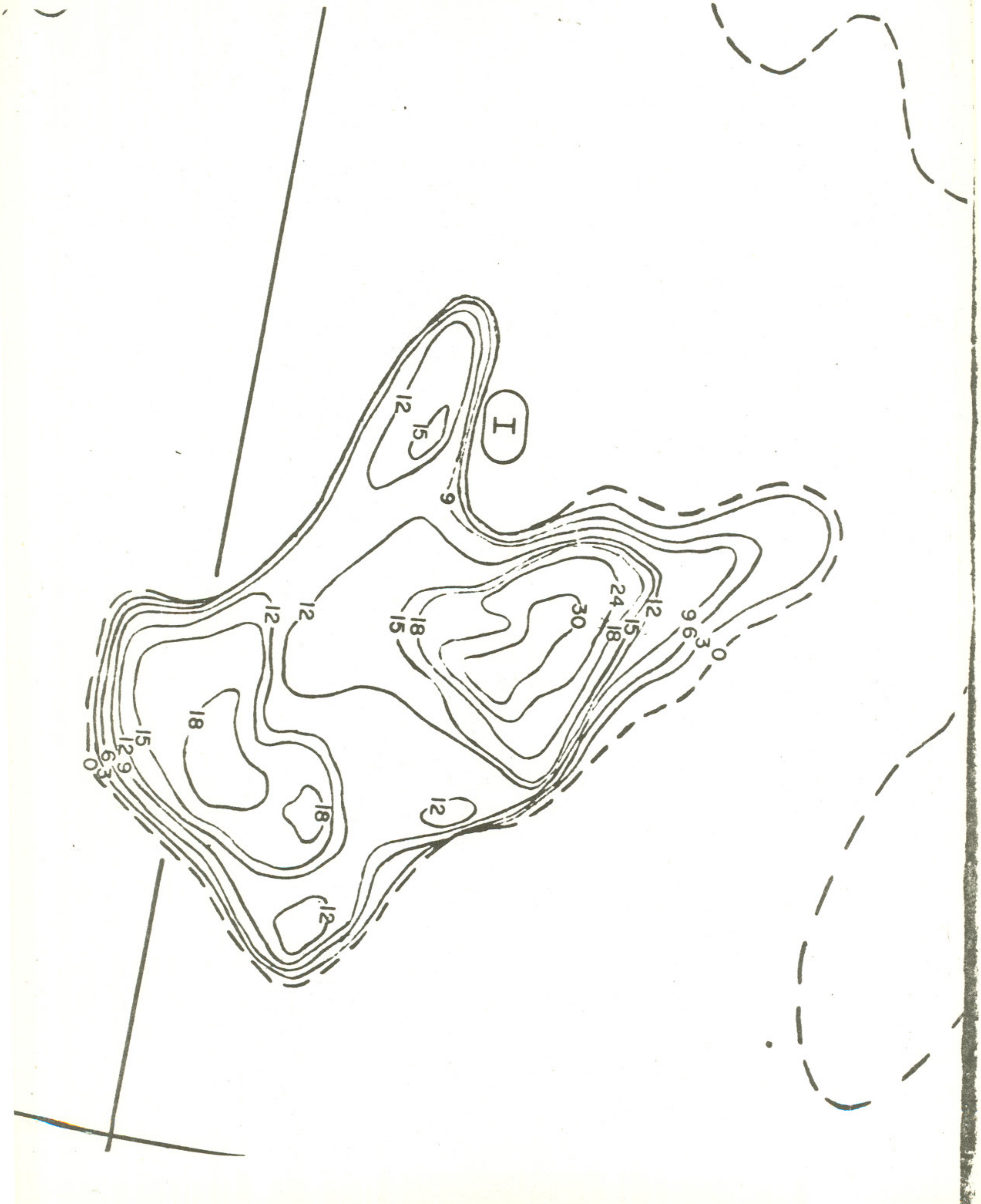
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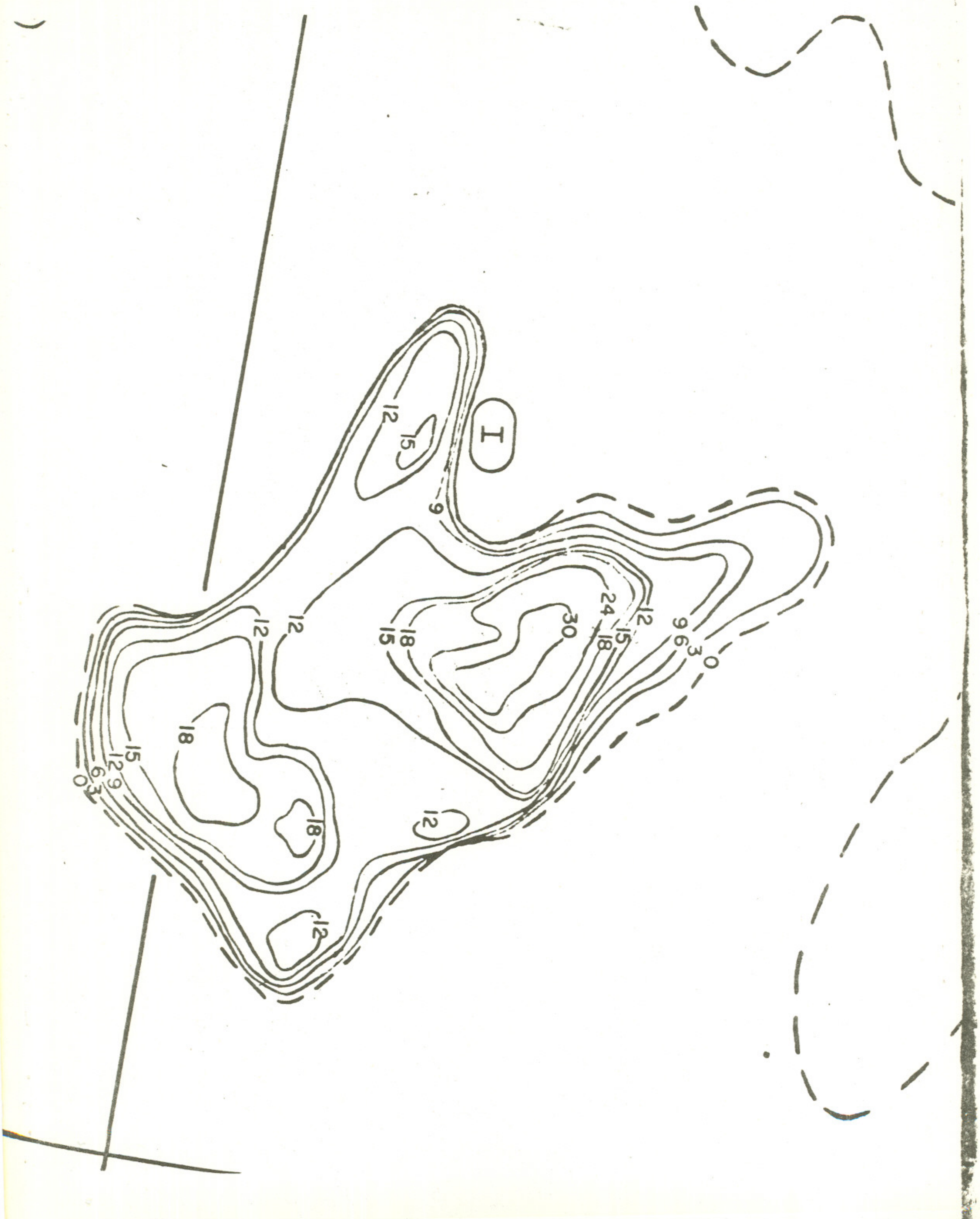

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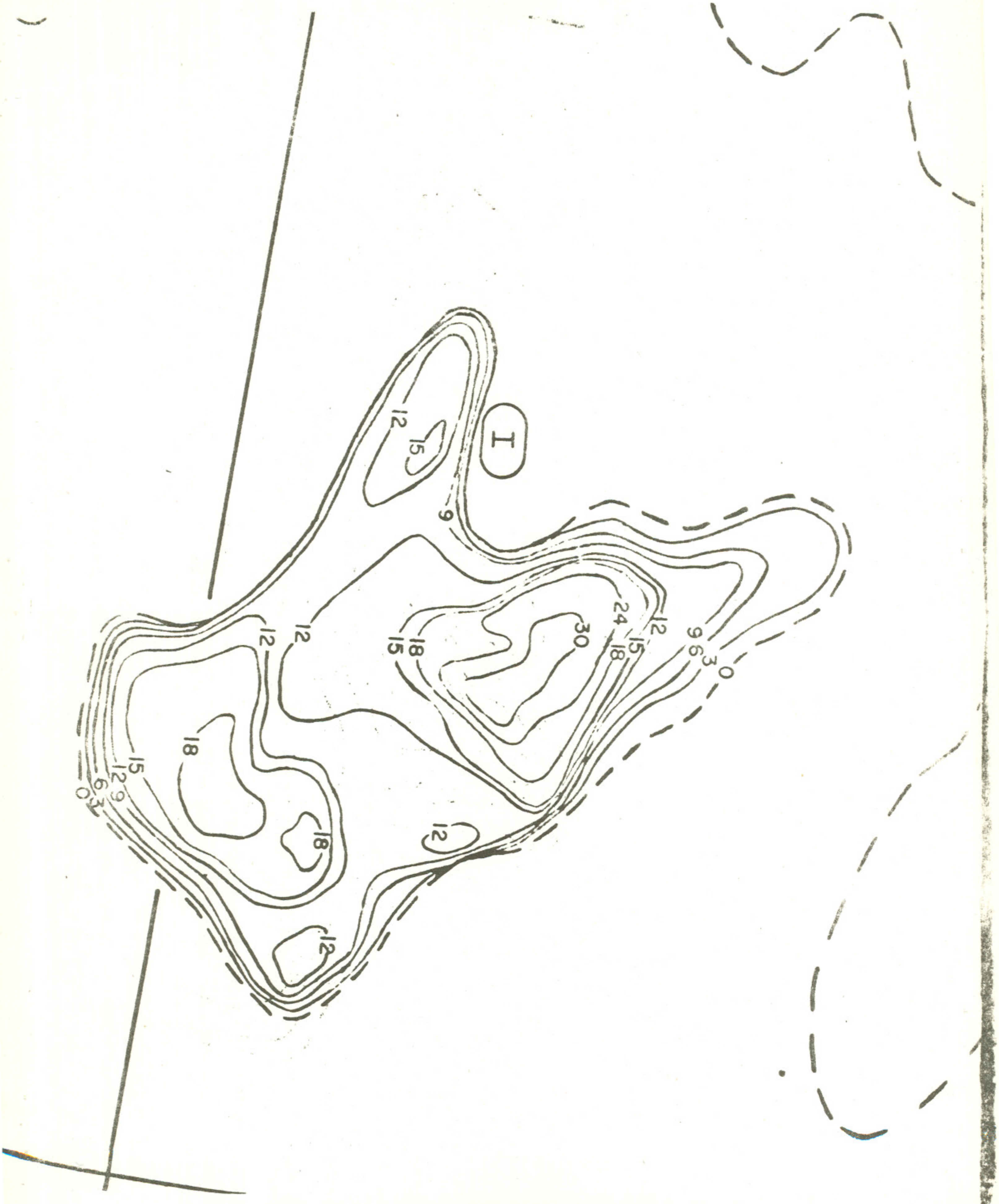
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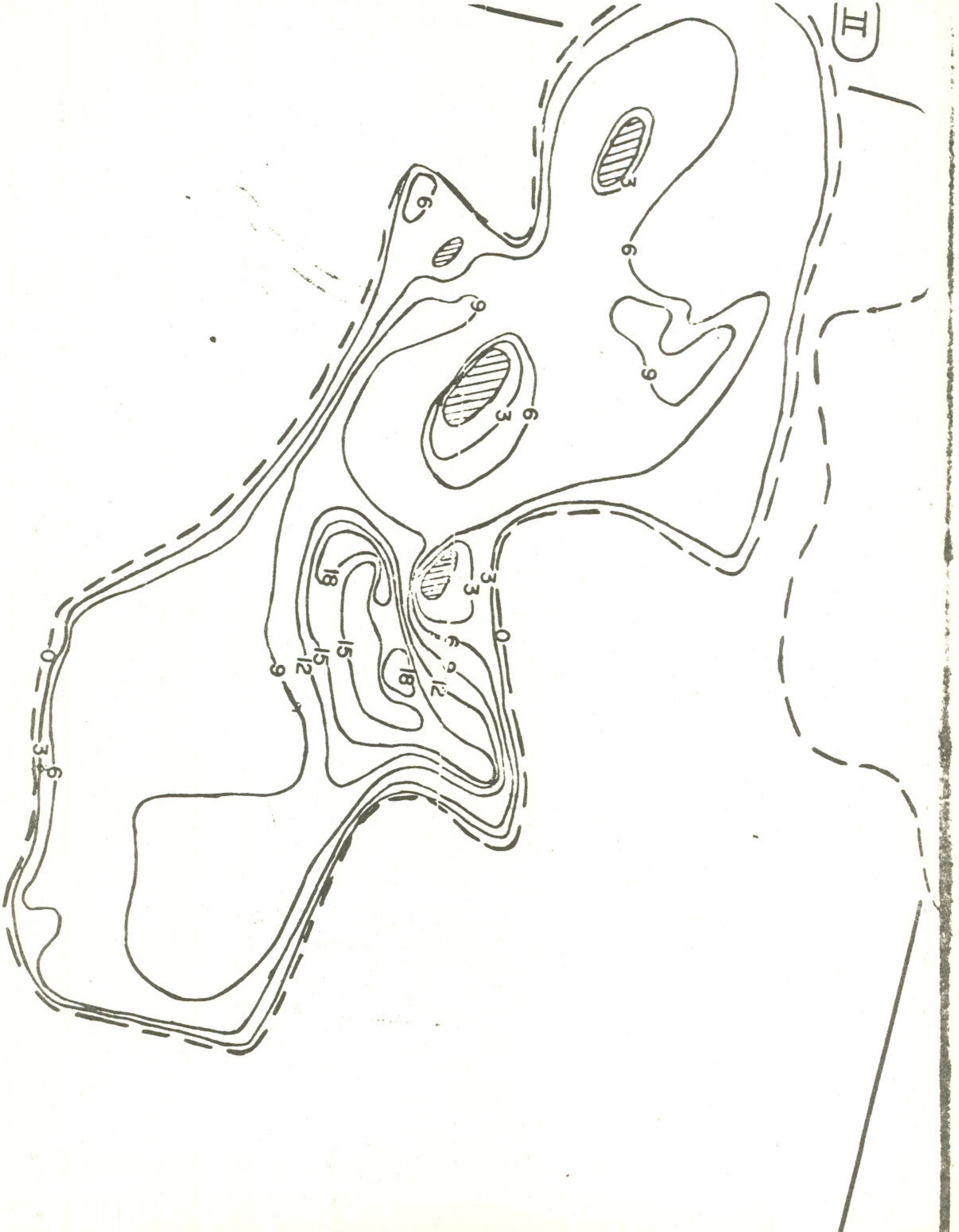
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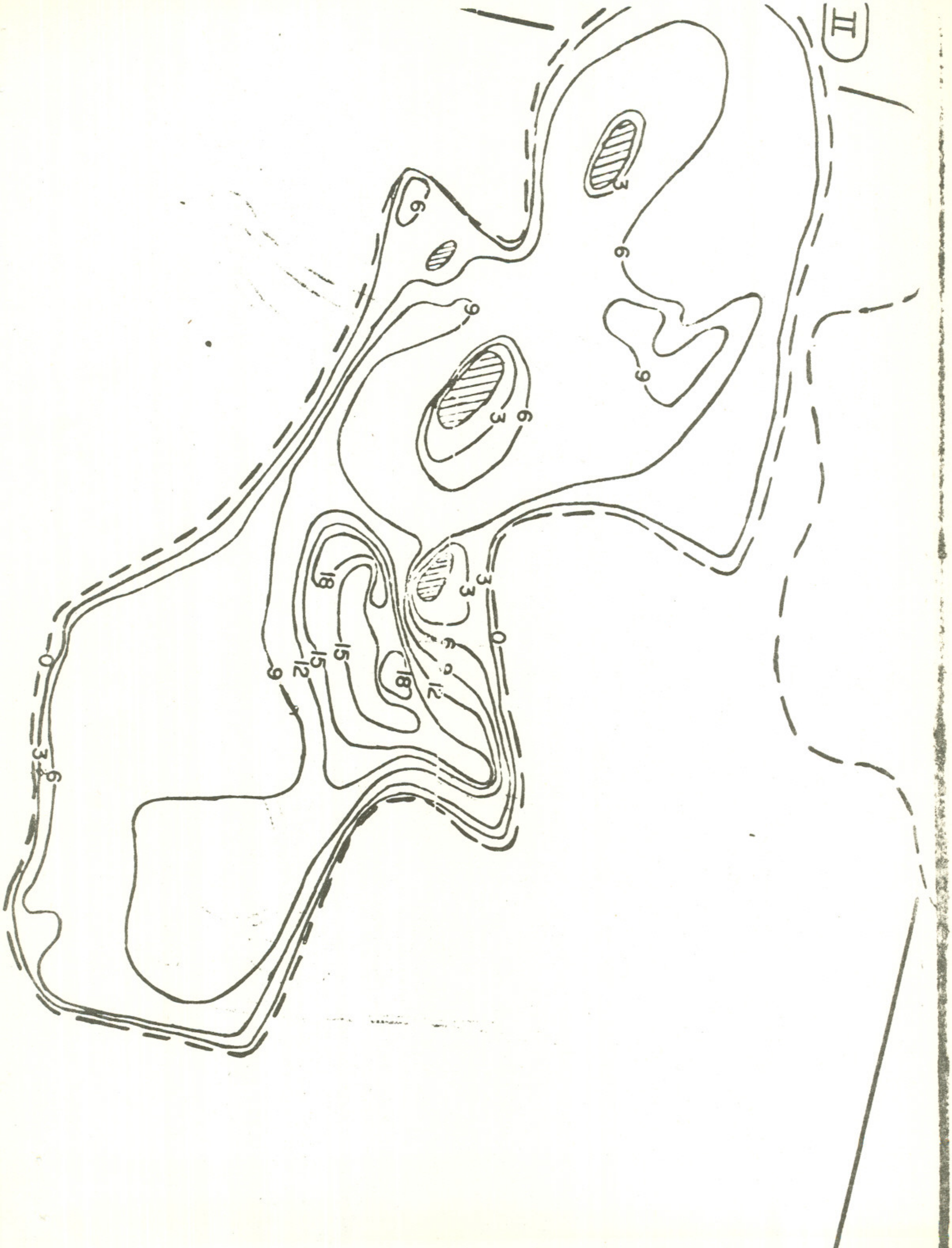
II
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