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Trips LS-2, LS-3

SEDIMENTOLOGICAL AND LIMNOLOGICAL STUDIES OF LAKE CHAMPLAIN

by

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INTRODUCTION

Lake Champlain, one of the largest lakes in the United States, represents a major water resource for the northeast as well as a source of recreation, transportation, and municipal water. Before 1965, very few data were available on the lake. In that year, a cooperative study was undertaken by workers in several departments at the University of Vermont including biochemistry, botany, engineering, geology, and zoology, to gain a better understanding of the lake's past history, present condition, and future prospects. The purpose of this trip is to demonstrate the type of research being done, and report some of the findings.

We would like to thank Drs. Milton Potash and Philip W. Cook for contributing data on general limnology and phytoplankton, and Richard Furbush, Master of the UVM Melosira, for many successful cruises. Without the help of our graduate students, who have been credited where appropriate, this report would not have been possible. The work upon which this research was based was supported in part by funds provided by the U. S. Department of Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379.

Present Lake Champlain

Lake Champlain is approximately 110 miles long and has a maximum width of twelve miles, measured from the Little Ausable River, New York, to the shore of Malletts Bay, Vermont. It has a mean elevation of 92.5 feet above sea level and a water surface of 437 square miles (gross area 490 square miles). As discussed elsewhere (Hunt, Boardman, and Stein, 1971) Lake Champlain is composed of two morphologically distinct although interconnected north-south trending water bodies. The larger body is referred to as the main lake. The smaller water mass to the east, called the east limb, is connected with the main lake by three narrow passages. The lower third of the lake resembles a river in that its maximum width is one mile and its maximum depth 20 feet. The south end of the lake is connected with the Hudson River via locks of the Champlain Barge Canal. North of Crown Point, New York, the basin widens and deepens reaching a maximum depth of 400 feet near Split Rock Point.

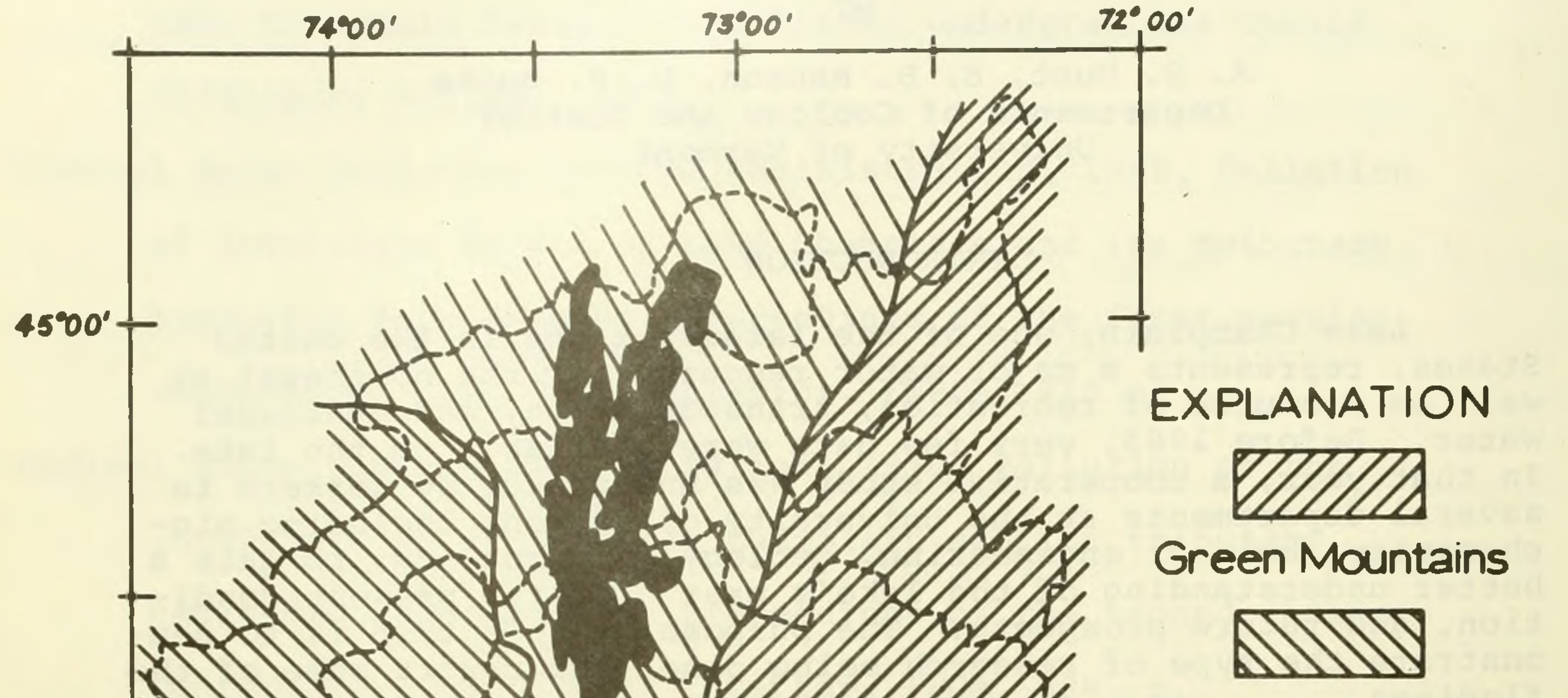
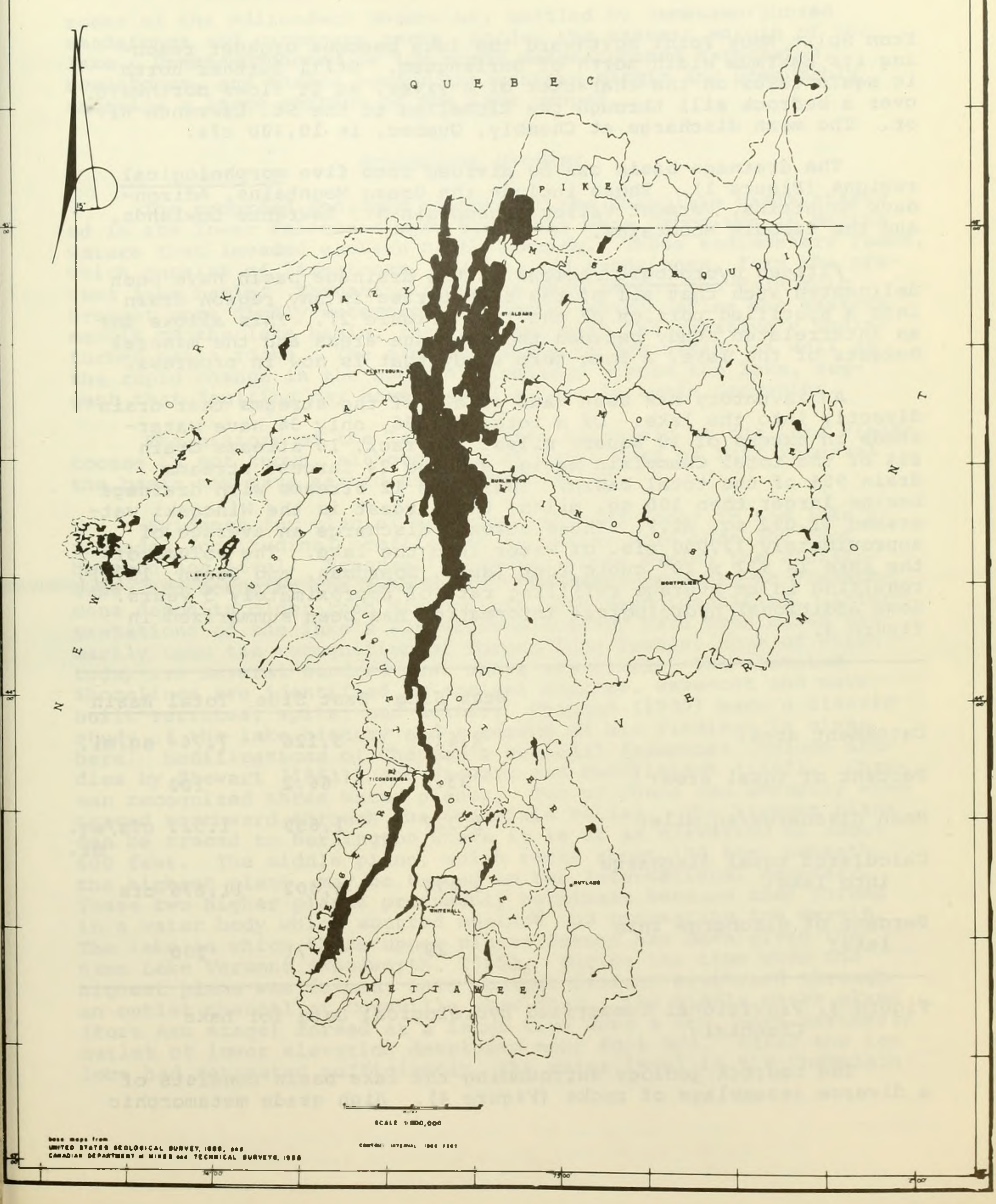


Figure 1. Morphological Regions of the Champlain Drainage Basin. The dashed lines designate drainage sub-basins. (From Hunt, Townsend, and Boardman, 1968).

Figure 2. The Lake Champlain Drainage Basin. (From Hunt, Townsend, and Boardman, 1968).



From Split Rock Point northward the lake becomes broader reaching its maximum width north of Burlington. Still further north it again takes on the character of a river, as it flows northward over a bedrock sill through the Richelieu to the St. Lawrence River. The mean discharge at Chambly, Quebec, is 10,900 cfs.

The drainage basin can be divided into five morphological regions (Figure 1). These include the Green Mountains, Adirondack Mountains, Vermont Valley, Champlain-St. Lawrence Lowlands, and the Taconic Mountains.

Fifteen hydrologic regions of the drainage basin have been delineated such that all of the tributaries in any region drain into a specified portion of the lake (Figure 2). This allows for an interrelated study between the drainage areas and the mineral budgets of the lake, a long-term study that is now in progress.

An inventory has been made of all of the streams that drain directly into the lake. Of a total of 296, only 34 have watersheds in excess of 10 square miles. In fact, 10 streams drain 80% of the total Champlain basin, and the 24 largest streams drain 95% of the total basin. There are 12 streams with drainage basins larger than 100 sq. miles; the largest is the Winooski watershed (1,092 sq. mi.). These streams discharge an average of approximately 12,000 cfs. of water into the lake. The volume of the lake is 912 x 10^9 cubic feet (Hunt, Boardman, and Stein, 1971), resulting in an average refilling rate of approximately 3 years. Some additional hydrological information has been summarized in figure 3.

	West Side	East Side	Total Basin
Catchment area:	2,618	5,126	7,744 sq.mi.
Percent of total area:	33.8	66.2	100
Mean discharge/sq.mile:	1.327	1.639	1.523 cfs/sq. mi.
Calculated total discharge into lake:	3,474	8,402	11,876 cfs
Percent of discharge into lake:	29	71	100

Figure 3. Provisional Summarized Hydrological Data for Lake Champlain.

The bedrock geology surrounding the lake basin consists of a diverse assemblage of rocks (Figure 4). High grade metamorphic rocks of the Adirondack Mountains, mantled by unmetamorphosed sandstones and carbonate rocks, border the western margin of the lake. Unmetamorphosed or low grade metamorphosed carbonates, sandstones, and shales border the eastern margin and presumably underlie a large portion of the lake proper.

GEOLOGICAL HISTORY

The recorded geologic history of the Champlain basin started in the lower Paleozoic when sediments were deposited in marine waters that invaded eastern North America. These sedimentary rocks, which consist of limestones, shales, and sandstones, form the present lake basin. Thrusting from the east during the Paleozoic brought more highly metamorphosed rocks, which define the eastern margin of the lake basin, into contact with the relatively undisturbed basin rocks. The elongate shape of the basin, as well as the rapid change in the bedrock lithology across the lake, suggest that faulting may have played a part in basin deepening.

The history of the lake from the Paleozoic to the Late Pleistocene is not known, although for at least part of this interval the basin may have served as a river valley.

Evidence for glacial scouring is found today in the lake's ungraded longitudinal profile and in basins more than 300 feet beneath sea level. Presumably several times during the Pleistocene, ice occupied the lake basin. To date, however, no Pleistocene deposits older than Wisconsinan have been identified. Interpretations of the lake's Pleistocene history have been based primarily upon the recognition of former lake levels, some of which today are several hundred feet above sea level. The elevated shorelines are identified by ancient beaches, wave-cut and wave-built terraces, spits, and deltas. Chapman (1937) made a classic study of the lake history and a résumé of his findings is given here. Modifications of Chapman's regional framework include studies by Stewart (1961), and Stewart and MacClintock (1969). Chapman recognized three water planes. Two of these end abruptly when traced northward through the Champlain Valley. The highest plane can be traced to Burlington where it is at an elevation of about 600 feet. The middle plane, which rests about 100 feet beneath the highest plane, may be traced to the International Boundary. These two higher planes presumably terminate because they formed in a water body which abutted against the retreating ice margin. The lake in which these upper planes formed has been given the name Lake Vermont (Woodworth, 1905). During the time when the highest plane was formed, Lake Vermont drained southward through an outlet channel at Coveville, New York. The middle water plane (Fort Ann stage) formed at a later time when a new, more northerly outlet of lower elevation developed near Fort Ann. After the ice lobe had retreated sufficiently, the water level in the Champlain

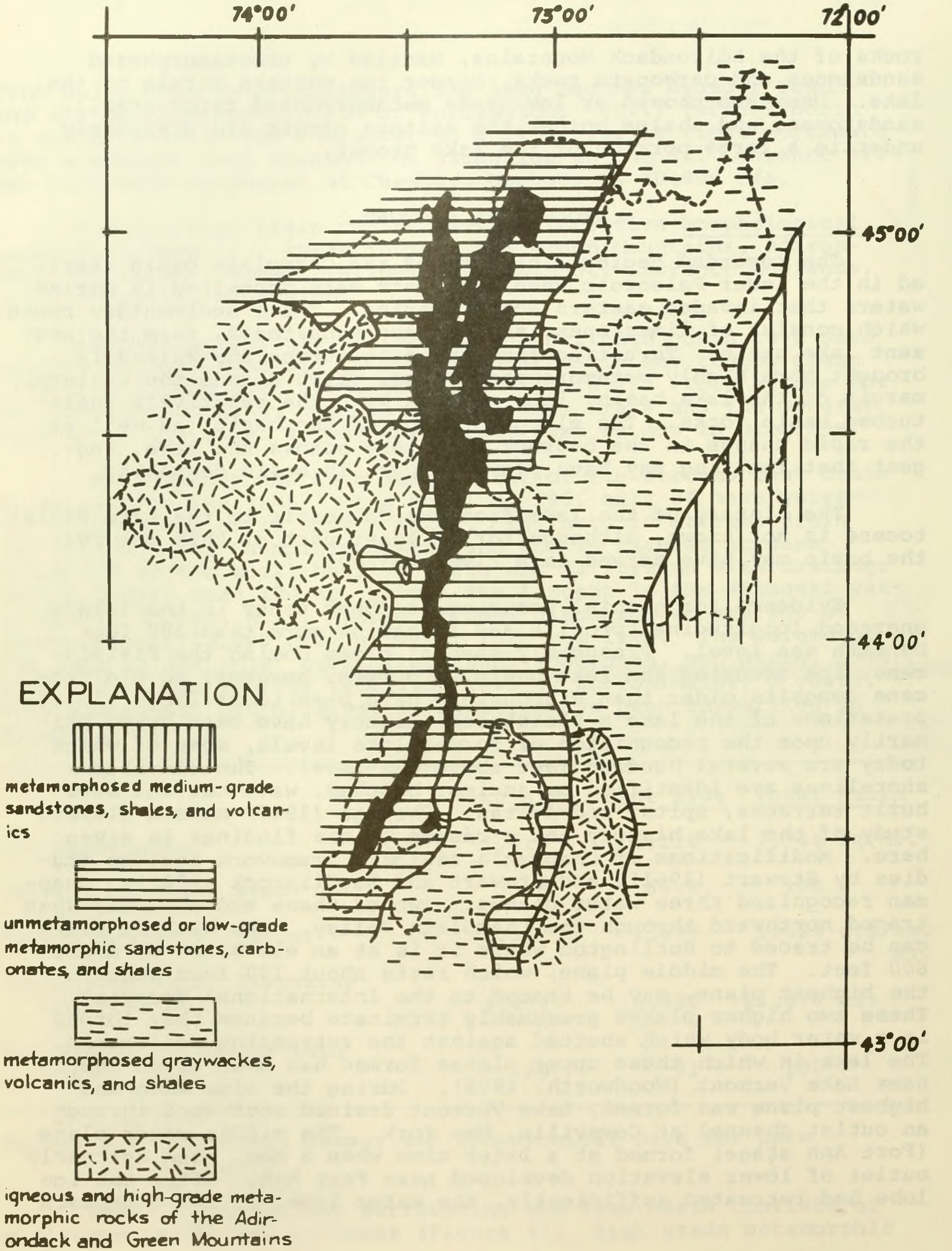


Figure 4. Major Rock Terrains of the Champlain Drainage Basins. The dashed lines designate drainage sub-basins. (From Hunt, Townsend, and Boardman, 1968).

Valley again dropped - this time several hundred feet, until it was continuous with marine water in the St. Lawrence lowlands. In the estuary which resulted, called the Champlain Sea, the lowest shorelines formed. Some time after the marine inundation the northern portion of the valley began to rise more rapidly than the southern portion. In time, the Richelieu threshold just north of the International Boundary was effective in preventing marine waters from entering the valley and the existing fresh water lake developed. Future tilting of only four-tenths of a foot per mile would cause Lake Champlain to again drain southward. This is only a small fraction of the tilting which has taken place since the Champlain basin was inundated by marine waters.

WATER PROPERTIES

Temperature:- The major portion of Lake Champlain can be considered to be a deep cold-water mesotrophic lake. Technically, it is classed as a dimictic lake (Hutchinson, 1957). This means that it has two periods during the year when the water in the lake is of equal temperature and is mixing. These periods of mixing alternate with periods of thermal stratification.

Thermal stratification begins to develop in June, and is well established in July and August. During mid-summer the metalimnion is at a depth of approximately 15 meters and includes the 12°C - 18°C isotherms. The period of summer stratification is short, for the depth of the thermocline increases steadily through August and September until the fall overturn takes place in October or November. Bottom temperatures in deep water remain at about 6°C during summer, but may rise to 12°C at the onset of the fall overturn.

The waters in the southern end and in the northeastern region of the lake are somewhat warmer than in the main lake, and warmer water is found in the bays along both shores.

During the winter most of the lake freezes over, and inverse thermal stratification develops with 4°C water at the bottom and 0°C water under the ice. Freezing begins in the narrow southern end, in the northern end, and in the northeastern portion of the lake. The wide main body of the lake is the last to freeze. In mild winters this portion may remain open throughout the winter season. The duration and intensity of the freeze depends on the severity of the winter.

Transparency:- The transparency of the lake, measured with a Secchi disc, ranges from about 3 to 6 meters. The deeper readings are encountered in late summer when algal growth is less. The disc reading in the southern part of the lake is usually less than 1 meter. Legge (1969) measured the penetration of light in the lake, using a submarine photometer. Ten percent of incident light was usually found at a depth of 3 meters, 5 percent at 5 meters, and 1 percent at approximately 10 meters. The level of 1 percent incident light is therefore above the level of the thermocline.

pH and Alkalinity:- Champlain is an alkaline lake. The pH of surface water is above 8.0, but in the deep water the pH may get as low as 7.3.

The total alkalinity in the main lake, predominantly as bicarbonate, ranges between 38 and 46 mg/l, and averages 41 mg/l. Alkalinity values are higher in the southern end of the lake, and minimal values are found in the water in the northeastern sector. Abnormally high values are sometimes encountered at stations close to shore, modified by tributary inflow. The alkalinity at Rouses Point, near the outlet of the lake, is actually less than that of the main lake.

Major Cations:- The four major cations (Ca, Na, Mg, and K) have been measured in the lake and the results are summarized in Potash, Sundberg, and Henson (1969a). In the main lake the concentrations of these four cations are ranked in descending order as Ca, Na, Mg, and K, with median values of 15.8, 3.9, 3.6, and 1.1 mg/l. In the southern part the descending rank order is Ca, Mg, Na, and K, with median values of 24.4, 5.8, 5.1, and 1.2. In flowing from the south to the central lake, the water is diminished in the concentration of all four cations, especially in magnesium. The concentrations in the northeastern region of the lake are significantly less than in the main lake. In this part of the lake the descending rank order is Ca, Na, Mg, and K, the same as for the main lake, but the median values are 13.2, 3.0, 2.9, and 1.3 respectively. It is suspected that these differences between the main lake and the northeastern portion of the lake are influenced, in part, by ground-water intrusion, while the differences between the main lake and the southern lake are a result of surface inflow.

Major Anions:- The dominant anion in the lake water is the bicarbonate ion, which is mentioned under alkalinity. A few determinations have been made of the chloride and the sulphate ions. In the main lake the median concentration of sulphate is 15.4 mg/l, and of Cl, is 5.7 mg/l. The pattern for these anions is the same as for the cations; values are higher in the southern end of the lake, and lower in the northeastern part of the lake.

Dissolved Oxygen:- The concentration of oxygen dissolved in the lake water is one of the more significant parameters measured in lakes; it is essential for respiration for all animals and most plants, it facilitates the decomposition of organic matter in the lake, and it serves as an index for the general quality of the lake water. The major sources of oxygen dissolved in the water are from exchange with the atmosphere and from photosynthesis by the plants in the lake. Oxygen is lost through respiration, decomposition, and increased temperature. The crucial test is the amount of oxygen in the deep water below the thermocline. In the deep water there is no source of new oxygen, and the supply that is there when stratification begins must last for the entire summer until the fall overturn mixes the water and carries down a new supply.

The trophic standard of a lake is sometimes measured by the concentration of dissolved oxygen in the deep water. In an oligotrophic lake the amount of organic material in the deep water during the period of summer stratification is of such small magnitude that oxygen consumed by decomposition has little effect on the concentration of oxygen in deep water. In a eutrophic lake, however, decomposition in deep water is great enough to reduce significantly the concentration of oxygen.

The main body of Lake Champlain is considered oligotrophic to mesotrophic by the oxygen standard. The lake water was more than 90 percent saturated in April, 1967, after the break-up of the ice cover. The oxygen in deep water from August through October was slightly less than 80 percent of saturation.

In some sheltered areas of the lake, for example, Malletts Bay, deep-water oxygen may be reduced to less than 1 percent of saturation (Potash, 1965; Potash and Henson, 1966; Potash, Sundberg, and Henson, 1969b). These are considered to be eutrophic areas of the lake.

BIOLOGICAL ASPECTS

Phytoplankton:- The phytoplankton is dominated by diatoms and blue-green algae. Asterionella, Diatoma, Melosira, and Fragilaria are dominant genera during the spring. Ceratium may become the dominant organism during mid-summer and the late summer-autumn plankton is characterized by the abundance of Tabellaria, Gomphosphaeria, and Anabaena. Overall, the phytoplankton is characteristic of a mesotrophic lake. Muenscher (1930) described the algae of the lake for 1928. Sherman (1972) has studied the diatoms in lake cores.

Zooplankton:- Ten species of Copepods (7 genera) and 12 species (9 genera) of Cladocora have been recorded from the lake. Among the Cladocera, Bosmina, Daphnia, and Diaphanosoma were the most abundant and widely distributed. Diaptomus and Cyclops were the only ubiquitous copepods. Dinobryon was found to be the most common Protozoa. Legge (1969) has described the seasonal distribution of the calanoid copepods in the lake.

Benthos:- The shallow-water (littoral) benthos consist of the usual communities of molluscs and insect larvae. The deep-water fauna in organic silt consists of small worms, the glacial relic shrimp Pontoporeia, small clams, and a larval chironomidae.

Relic Pleistocene Fauna:- The fauna of Lake Champlain includes several species that are considered to be relics of the Pleistocene. Most of these animals are small invertebrates associated with the cold, deeper waters of the lake. They are mainly among the Crustacea. The schizopod species Mysis relicta (Opossum shrimp), a form common to the Atlantic Ocean, is found. Another inhabitant is the amphipod shrimp, Pontoporeia affinis, which was discovered in this lake only within the last five years. Both of these animals are common in the Great Lakes, but apparently are not very abundant in Lake Champlain. According to present thought these two species were able to inhabit the Pleistocene proglacial lakes and migrated from the Baltic Sea area during the Pleistocene, using a path around the Arctic Ocean, down through the Canadian chain of lakes, through the Great Lakes, to Lake Champlain (Ricker, 1959; Henson, 1966). Lake Champlain represents a terminus for these animals. Pontoporeia has not been found north of the St. Lawrence River east of the Ottawa River. Presumably an ice block prevented their migration into this area of the continent. There are some other animals in the lake which also are considered to be glacial relics. Among the small crustacean zooplankton would be included Senecella calanoides, which was first described from one of the Finger Lakes of New York, and Limnocalanus macrurus.

STRATIGRAPHY AND SEDIMENTARY HISTORY OF THE LAKE

Recent Sediments

The sediments exposed on the lake bottom today consist predominantly of materials deposited since the end of the Champlain Sea episode (about 10,000 years B.P.). The source of this material is (1) unconsolidated glacial deposits transported to the lake basin by streams (2) bedrock eroded from the shoreline; (3) organic matter from decomposing plants and animals; (4) biochemical constituents such as diatom frustrules. Based upon the size of past and present lake deltas, it is apparent that rivers have played an important role in transporting sediments to the basin. The present distribution of lake sands and gravels may be explained by wave winnowing. Coarse material, transported by streams to the lake is being left near shore. Fine material is being carried to the deeper basins. The lake muds, which constitute the deep water facies of the near shore sands and gravels, contain a significant fraction of organic matter, as well as biochemical constituents. With the possible exception of deltaic deposits which have not yet been studied, lake muds constitute the thickest sequences of recent sediments. Thicknesses of up to 80 feet have been observed (Chase, 1972). For purposes of discussion, recent lake sediments have been grouped into four types - gravels, sands, lake muds, and iron manganese concretions. A description of these four sediment types is given below:

Gravels:- Gravel deposits, as defined by greater than 30 percent gravel (Folk, 1954), make up less than 4 percent of the sediments exposed on the lake bottom. Except for the gravel-sized material found in prerecent lake clays, gravels occur primarily in three areas: (1) shallow nearshore environments; (2) surrounding islands; and (3) at the mouths of rivers. Both in nearshore environments and surrounding islands the gravels represent lag deposits formed from the sorting of glacial till as well as the erosion of local bedrock. Gravels at the mouths of rivers are forming as a delta deposit. Former river channels can frequently be recognized by the distribution of nearshore gravel deposits.

Sands:- Sands, defined as having at least 30 percent sand (Folk, 1954), cover 22 percent of the lake bottom. The distribution of recent sand deposits is much like that of gravel in that they occur primarily in nearshore shallow water environments, and at the mouths of rivers (Fig. 5). In many areas they grade shoreward into gravels. The sands are low in organic matter, carbonate content, and are texturally and mineralogically immature.

Muds:- Muds cover approximately three quarters of the total area of the lake bottom. They occur primarily offshore in deep water (greater than 50 feet) where wave action is at a minimum, and in sheltered areas such as the bays. They are continuous through a facies change with recent sands. The surface of the muds is a grayish to reddish brown hydrosal. Beneath the interface, the muds are dark gray, uniform in grain size, and generally without lamination or structures although carbon smears and mottling do occur. The muds typically have a high organic content (up to 20 percent). The inorganic constituents of the muds consist of silica grains, clay minerals, and, in some areas, greater than 50 percent diatom frustrules.

Iron-Manganese Concretions:- "Manganese nodules" have been discovered in seven areas of Lake Champlain (Fig. 6). Only in the east limb, however, are they abundant and do they form well-developed concretionary structure. Here they occur in an almost pure state. In other areas the concretions are mixed with a terrigenous matrix which constitutes 90 percent or more of the sample. They occur primarily on shallow water platforms in water depths less than 40 feet and in areas where sedimentation rates are low (Fig. 6). Where concretions do occur at greater depths, they are found on slopes adjoining shallow water shelves, suggesting transportation off the shelves and down the slopes after formation. The nodules are associated with sandy sediments indicating that they are forming in high energy environments (Johnson and Hunt, 1972).

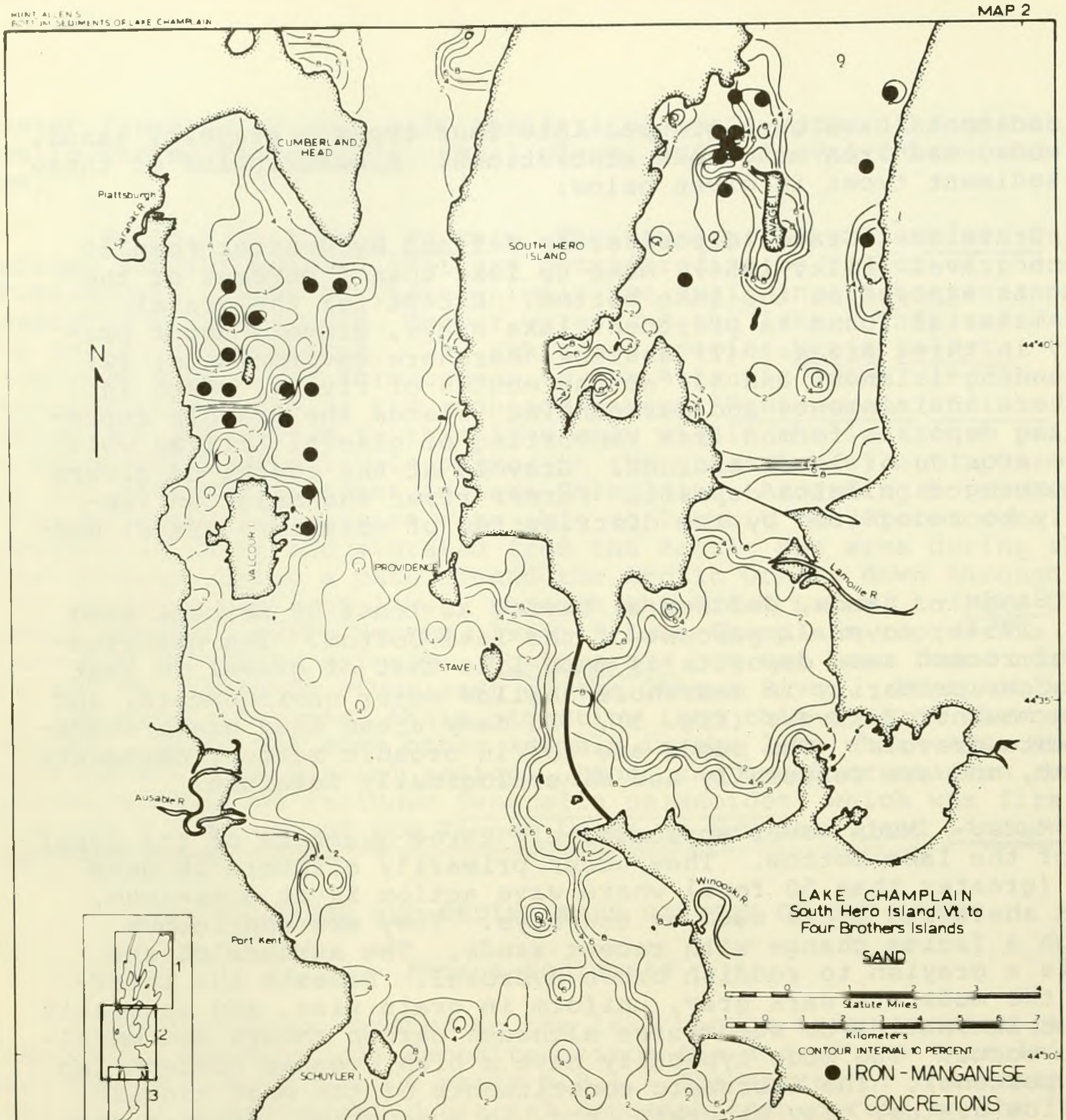


Figure 5. The Distribution of Sand in Central Lake Champlain.

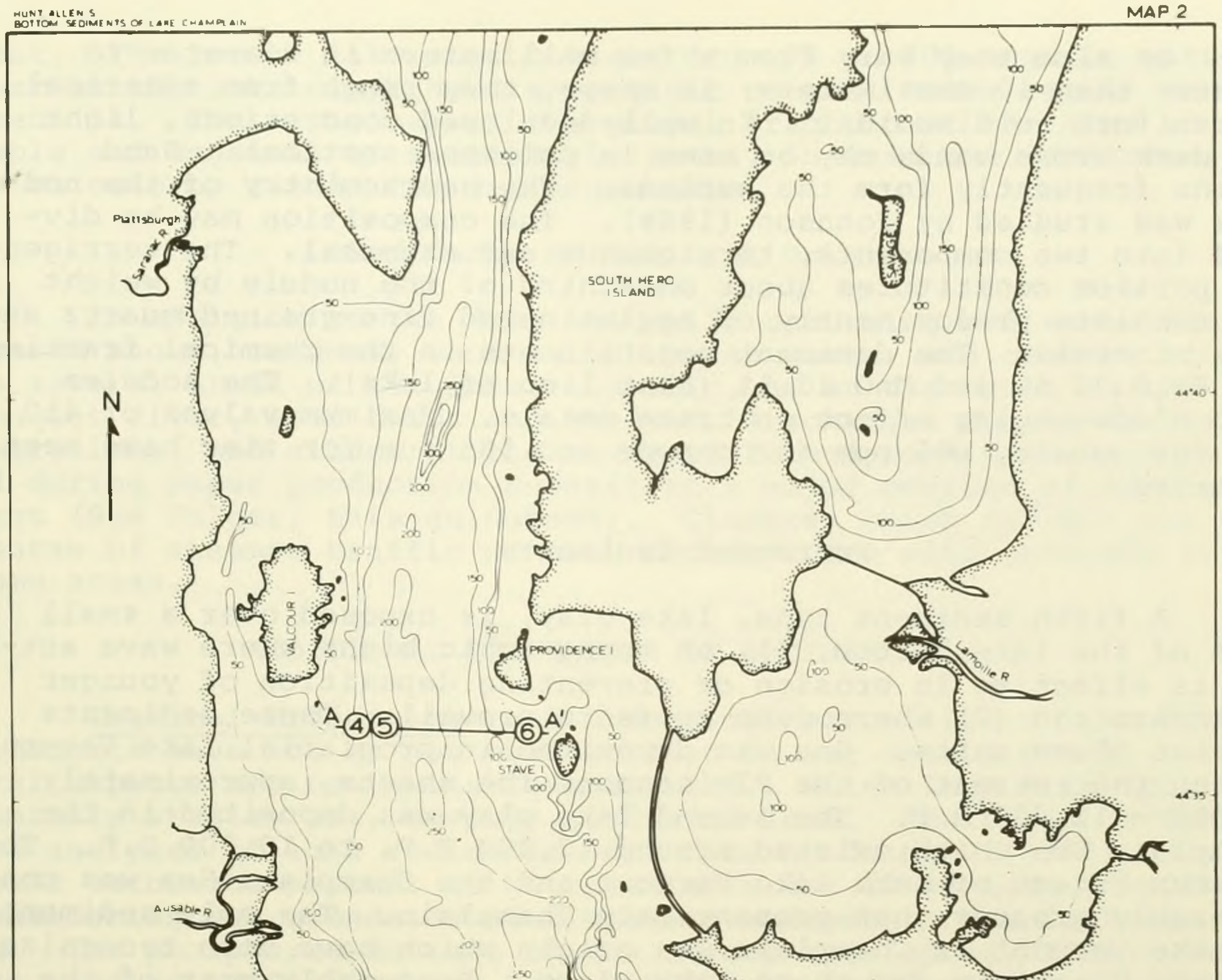


Figure 6. Bathymetry, Profile Locations, and Sampling Sites, Central Lake Champlain.

In size they vary from a few millimeters in diameter to greater than 10 centimeters; in shape, they range from spherical to reniform to discoidal. In well-developed concretions, light and dark brown bands may be seen in polished sections. Sand grains frequently form the nucleus. The geochemistry of the nodules was studied by Johnson (1969). The composition may be divided into two components, terrigenous and chemical. The terrigenous portion constitutes about one-third of the nodule by weight and consists predominantly of agglutinated fine-grained quartz and clay minerals. The dominant constituents in the chemical fraction are Fe_2O_3 38.5% and MnO 10.5% (east limb of lake). The nodules have a scavenging effect on trace metals. Maximum values of 410 ppm for cobalt, 605 ppm for copper and 585 ppm for zinc have been observed.

Prerecent Sediments

A fifth sediment type, lake clay, is exposed over a small area of the lake bottom, (1) on topographic highs where wave action is effective in erosion or preventing deposition of younger sediments and (2) where deep currents prevail. These sediments consist of two units. One was deposited in proglacial Lake Vermont during the retreat of the Pleistocene ice sheets, approximately 13,000 - 12,000 B.P. The second lake clay was deposited in the Champlain Sea which existed around 12,000 B.P. to 10,000 B.P. The maximum extent of both Lake Vermont and the Champlain Sea was considerably greater than present Lake Champlain. The only sediments of Lake Vermont or Champlain Sea origin which have been recognized in Lake Champlain are these lake clays. Presumably most of the coarser nearshore facies have been stranded away from the lake at higher elevations. These two units have been traced subsurface by sub-bottom profiling (Chase, 1972). Champlain Sea sediments, which have a known maximum thickness of about 100 feet, may be most easily recognized by the presence of foraminifera. More than a dozen genera have been recognized by Egolf (1972) from a single core at the mouth of Shelburne Bay. No fossils are known from the underlying Lake Vermont unit which has a total thickness in excess of 150 feet. Bedrock or till is believed to rest beneath these lake clays. A description of the lake clays, as exposed on the lake bottom today, is given below.

The clays are dense, sticky, and extremely poorly sorted, containing material ranging from clay size to cobbles several inches in diameter. Larger particles, including sand and gravel, are concentrated at the sediment-water interface and are dispersed through the sediment to a depth of at least several feet beneath the surface. The water-sediment interface is not a hydrosol as it is with the recent muds but is so well-compacted that it is difficult to penetrate. Wet, the clays typically are brown to yellow-brown in color at the interface and dark brown to dark grey below it. The clays also differ from the muds in their low organic content. The recent lake muds contain from 5% to 20% organic matter, whereas the lake clays have an organic content which rarely exceeds 5%. The lithology of the gravel fraction of the clay is variable and consists of metamorphic rocks, shales, and sandstones which outcrop within the drainage basin.

Sediments of Cultural Origin

In addition to the five naturally occurring sediments discussed above, sawdust, wood chips, paper waste, and cinders occur in several areas of the lake. Locally, as at the mouth of the Bouquet River, wood chips and sawdust, discharged during lumbering operations, and sludge at the mouth of Ticonderoga Creek discharged during paper production constitute a major portion of the sediment (See Folger, this guidebook). Cinders, which reflect the course of steamer traffic of past decades, are also abundant in some areas.

ADDITIONAL PROPERTIES OF SEDIMENTS

Chemical Properties:- The chemical properties of the lake sediments have not as yet been studied in any detail though several aspects are now being investigated. Notes from a few preliminary studies are, however, included here. Scattered carbonate analyses of lake sediments were made by Johnson (1967) who found carbonate percent to be remarkably low (less than 2 percent), considering the abundance of limestone bedrock in the drainage basin. The phosphorus content of the recent muds of St. Albans Bay was studied by Corliss and Hunt (1971) who found values twice as high in St. Albans Bay (1100 ppm) as in Lapan Bay, the control bay, which suggests nutrient build-up, presumably resulting from the discharge of sewage by the Town of St. Albans. Analyses of trace metals include the work of Cronin (1970) who analyzed the lead content in sediments taken on a traverse from Burlington Harbor westward to central Lake Champlain. He found that the highest concentrations occur in Burlington Harbor. Additional analyses by Hunt of lead, zinc, and chromium suggest that surface sediments have a higher concentration than underlying sediments, indicating cultural pollution. Chase (1972) analyzed for calcium and magnesium in sediment and interstitial waters of lake cores. Some variations were found but the interpretation of these data is not yet clear. An extensive study of trace metal concentrations utilizing core data is now underway by April (1972).

Organic Properties:- About 500 surface samples, primarily from central Lake Champlain, have been analyzed for total organic matter (Hunt, 1971). Values range from less than 1% to 22%. The data show that (1) organic content increases from the shoreline lakeward, (2) is positively correlated with increasing water depth, (3) increases with decreasing grain size. Numerous exceptions to these generalizations do occur. Some are easily explained, as in the vicinity of Ticonderoga Creek where organic values of 22% were observed. This organic matter almost certainly is a product of industrial pollution (see Folger, this guidebook).

Mineralogical Properties

Heavy Minerals:- Townsend (1970) studied the heavy mineral content of sediments from the Ausable and Lamoille Rivers. He recognized two mineral assemblages: one, present in the western portion of the lake, is derived from the igneous and metamorphic rocks that occur in the drainage basin to the west. The second assemblage is best developed on the east shores of the lake and reflects the lower grade metamorphic source rocks which are exposed in the eastern portion of the drainage basin. In the central portion of the lake these two assemblages mix.

Clay Minerals:- Studies of clay-mineral distribution within the confines of Lake Champlain are in their infancy. Millett (1967) conducted X-ray diffraction studies of approximately 100 surficial sediment samples between Valcour Island, New York, and Thompson Point, Vermont. He found illite and chlorite are the dominant clay minerals with most samples having an illite:chlorite ratio in the range of 2.3 to 3.7. Some kaolinite is present in sediments from the Bouquet and Ausable Rivers which drain from the west side of the lake, but kaolinite appears to be essentially absent from lake sediments.

In addition, approximately 250 samples were checked by Bucke from 7 cores to determine clay mineral content vertically through the sediments. Millett's findings were supported in that the only significant clay minerals are illite and chlorite. The average illite:chlorite ratios in the cores range from 3.3 to 5.0 with a mean of approximately 4.2, about one higher than Millett's surface samples. This particular study was essentially a "shot-in-the-dark" with no previous knowledge of lithologies being penetrated by the cores. Current investigations of vertical clay mineral distribution is directed to determine if any consistent variations are detectable among Lake Vermont, Champlain Sea, and Lake Champlain sediments. Chase (1972) ran preliminary studies toward this end. Some suggestions of vertical variation are present, but as yet data is not consistent nor extensive enough to establish any real trends.

STOP DESCRIPTIONS

Stop 1. Telemetric buoy, Burlington Harbor. - We will pass alongside a buoy that has been installed by the Lake Champlain Studies Center to collect and transmit environmental data. The buoy normally transmits by radio every three hours to a base unit at the University which prints out the data in digital code. At present the buoy transmits information on wind speed and direction, air temperature, and water temperature at two depths. An accellerometer is being used in an attempt to measure sea state.

Stop 2. Reference Stations. - This stop, in 300 feet of water, is a reference station that has been sampled since 1965. A temperature profile will be obtained with a bathythermograph, demonstrating temperature variation with depth; and water samples will be collected at several depths for chemical analyses, and a plankton tow will be obtained for specimens of *Mysis*. In addition, a sample of recent lake muds will be collected.

Stop 3. Four Brothers Islands. - Cores from this area contain foraminifera indicating that these sediments were deposited in the Champlain Sea. The surface sediments on the Four Brothers rise contain a relatively high percentage of sand which distinguishes them from the encircling recent lake muds (Figure 5). The Four Brothers are situated on a topographic high and are subjected to extensive wave action, therefore, the sands may represent lag deposits rather than undisturbed pre-Lake Champlain sediments. The primary purpose of this stop is to obtain a piston core of Champlain Sea sediments.

Stop 4. Valcour Island. - This stop along with stops 5 and 6 will constitute a west-east traverse designed to show differences in thermal patterns, benthos, and sediment types across the lake. The interpretation of the sedimentary sequence based upon sub-bottom profiling data is given in figure 7. At this stop a bathythermogram will be taken and a grab sample will be collected and sieved for benthos. The waters surrounding Valcour Island were the site of the first naval engagement of the Revolutionary War.

Stop 5. Central Lake. - Sediments here are Champlain Sea deposits, underlain by Lake Vermont clays (Figure 7). At the surface the Champlain Sea deposits contain up to 40% sand as well as gravel-sized particles several inches in diameter, suggesting winnowing. Recent lake muds surrounding these Champlain Sea deposits indicate that restricted deep currents may be responsible for the winnowing.

Stop 6. Providence Island. - To complete the traverse profile a bathythermogram will be taken at this station, the benthos will be sampled, and a plankton haul will be made.

Stop 7. Winooski Delta (Optional) - This is a shallow-water stop at the mouth of the Winooski River. The influence of the river on the lake's bathymetry may be seen in figure 5. The sediment contains up to 80% sand. The area was considered by engineering firms as a source of fill in the construction of the Burlington beltline but a more economical land source was eventually selected. Deposition from the Winooski and Lamoille Rivers has virtually isolated Malletts Bay from the main lake. Note the tombolo forming the railroad crossing between the mainland and Grand Isle. As we return to Burlington Harbor, note the Champlain overthrust exposed on Lone Rock Point.

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