Trip B

RECENT SEDIMENTATION AND WATER PROPERTIES, LAKE CHAMPLAIN

by

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INTRODUCTION

Purpose

Within the last few years a considerable amount of research has been done on Lake Champlain. The purpose of this trip is to show what type of work is being carried out on the lake and to report some of the findings.

Acknowledgements

We would like to thank Dr. Milton Potash who contributed data on general limnology, Dr. Philip W. Cook who provided information on the phytoplankton, and Dr. W. Philip Wagner who read the manuscript. Many graduate students at the University of Vermont have contributed data as follows: Sander Sundberg is acknowledged for chemical information and Carl Pagel for data on bottom animals. Thomas Legge is credited for zooplankton data and seasonal aspects of the lake. Richard Clement contributed the data used in compiling the Malletts Bay portion of the sediment map of Lake Champlain and Peter Townsend supplied the heavy mineral analyses. Much of the information on iron-manganese concretions is credited to David G. Johnson.

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PRESENT LAKE CHAMPLAIN

Lake Champlain is approximately 110 miles long and has a maximum width of approximately 12 miles, measured from the Little Ausable River, N.Y., to the shore of Malletts Bay, Vt. It has a mean elevation of 92.5 feet above sea level and a water surface area of 437 square miles (gross area 490 square miles). The lake has a maximum depth of 400 feet near Thompson's Point and a mean depth of approximately 65 feet.

The lake drains northward through the Richelieu River into the St. Lawrence River. The mean discharge of the 8,234 square miles of the Champlain basin at Chambly, Quebec, is 10,900 cubic feet per second. At its southern end, Lake Champlain is connected, via several locks, with the Hudson River through the Champlain Canal.

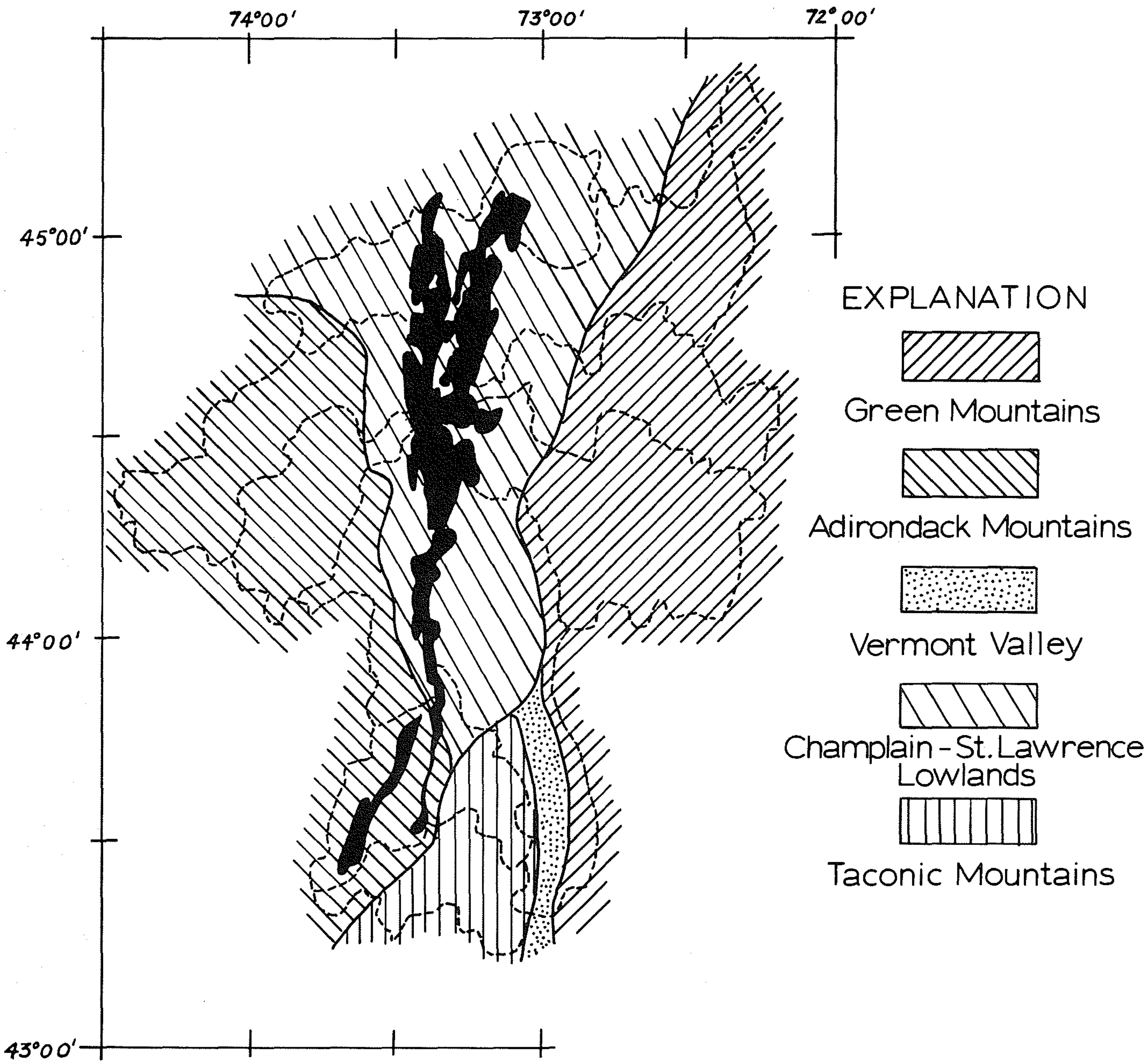


Figure 1 Morphological regions of the Champlain drainage basin. The dashed lines designate drainage sub-basins.

The Champlain Valley drainage basin (excluding area of the lake) is 7,744 square miles, of which about 34 percent is in New York to the west and 66 percent in Vermont and Quebec to the east and north. It may be divided into five morphological regions (Fig. 1). These include the Green Mountains, Adirondack Mountains, Vermont Valley, Champlain-St. Lawrence lowlands, and the Taconic Mountains. Twelve sub-basins have been recognized within the Champlain Valley drainage basin: Chazy, Saranac, Ausable, Bouquet, Lake George and Mettawee in New York; the Pike in Quebec; and the Missisquoi, Lamoille, Winooski, Otter, and Poultney in Vermont. The Missisquoi and Chazy also drain portions of Quebec (Hunt, Townsend and Boardman, 1968). Six tributaries, each with a catchment area greater than 500 square miles, drain 52 percent of the entire drainage basin. These are the Otter Creek, Winooski, Lamoille, Missisquoi, Saranac, and Ausable. As a first approximation the mean annual discharge into the lake from the drainage basin is 11,900 cubic feet per second. Given a mean discharge from the lake of 10,900 cubic feet per second and an estimated lake volume of 9.12×10^{11} cubic feet (Boardman, Hunt, and Stein, 1968), the mean retention period of the lake is slightly less than three years. Some additional hydrological data have been summarized in Figure 2.

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

Figure 2. Provisional summarized hydrological data for Lake Champlain

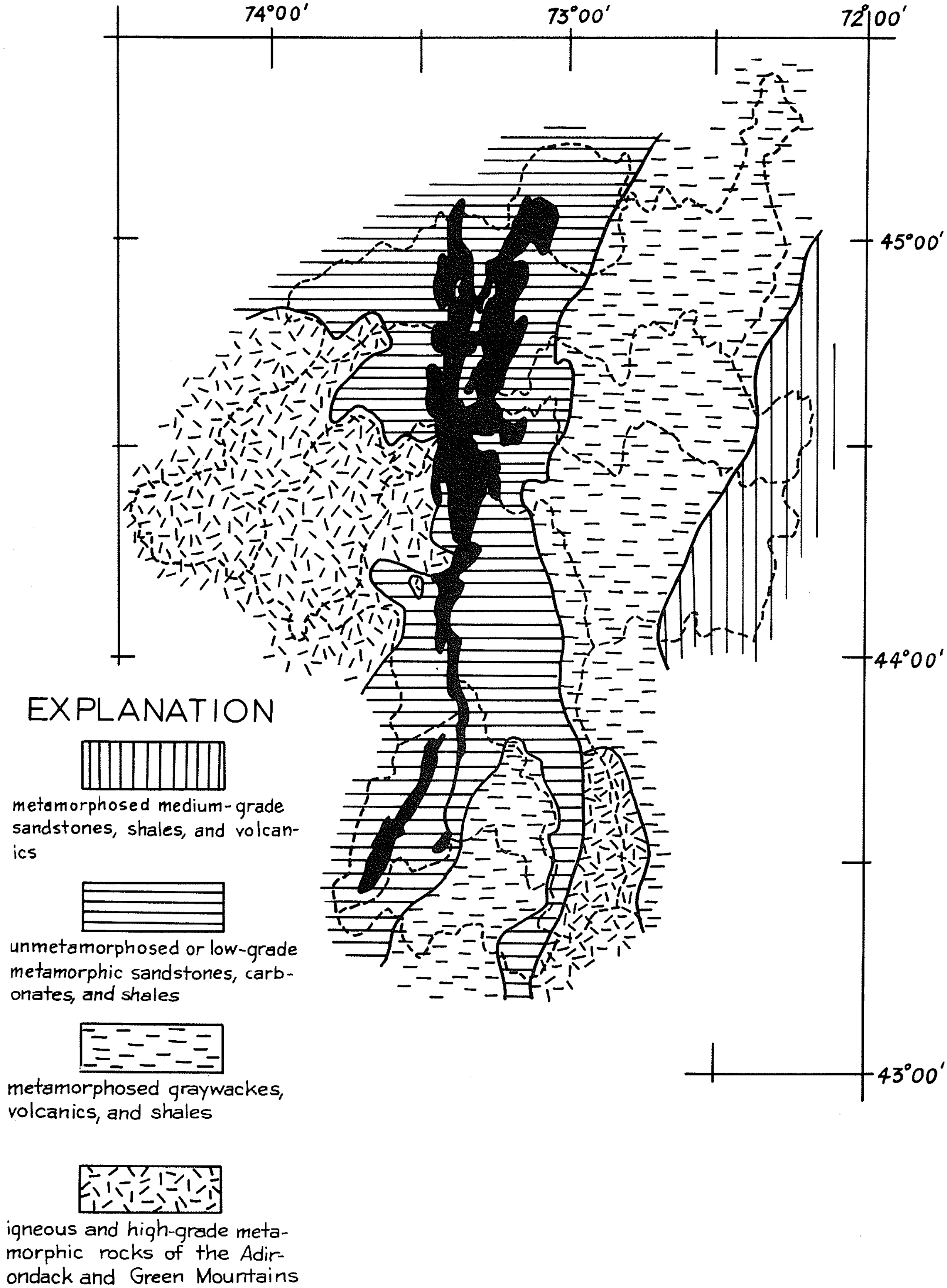


Figure 3 Major rock terrains of the Champlain drainage basins. The dashed lines designate drainage sub-basins.

The bedrock geology surrounding the lake basin is made up of a diverse assembledge of rocks (Fig. 3). 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 deepening the basin.

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.

Possibly several times during the Pleistocene, ice occupied the valley. To date, however, no Pleistocene deposits earlier than Wisconsin have been identified in the Champlain basin. Evidence for glacial scouring may be found today in the lake's ungraded longitudinal profile and in basins more than 300 feet beneath sea level. The last lobe of ice is believed to have been present in the Champlain Valley during the Mankato substage (Stewart, 1961, p. 84). Although field studies are presently being conducted by Dr. W. Philip Wagner (see Trip D of this guidebook), the most complete study presently available of the Pleistocene history of Lake Champlain was done by Chapman (1937) and the résumé given here is taken from his work. Interpretations of the lake's Pleistocene history are based primarily upon the recognition of former lake levels, which today may be several hundred feet above sea level. The elevated shorelines are identified by finding ancient beaches, wave-cut and wave-built terraces, river deltas, and outlet channels. These features do not occur at random elevations, but form several planes which have been interpreted as ancient lake stands that formed as lake level temporarily remained stationary. Chapman recognized three water planes. Two of these end abruptly when traced northward through the Champlain Valley. The highest plane may be traced to Burlington and the middle plane to the International Boundary. The two higher planes presumably terminate because they formed in a water body which abutted against the retreating ice margin. The lake in which these planes formed has been given the name

Lake Vermont.[1] During the time when the highest plane recognized by Chapman was formed, which he called the Coveville stage, Lake Vermont drained southward through an outlet channel at Coveville, New York. The lower water plane, which also drained to the south, formed at a later time when a new, more northerly outlet of lower elevation developed near Fort Ann. The water level of Lake Vermont dropped about a hundred feet between the Coveville and the Fort Ann stage. After the ice lobe had retreated from the St. Lawrence Valley, the water level in the Champlain Valley dropped several hundred feet and was continuous with marine water in the St. Lawrence Valley.[2] No appreciable tilting of the basin occurred (Chapman, 1937, p. 101) from the time that the Coveville plane was developed until the invasion of marine water, correlated with Two Creeks interval (Terasmae, 1959, p. 335). Some time after the inundation by marine water, however, the northern portion of the valley began to rise more rapidly relative to the southern portion. In time, the Richelieu threshold just north of the International Boundary became 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 allow Lake Champlain to drain southward as during Lake Vermont (Chapman, 1937, p. 122). 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 are alternated by periods of thermal stratification.

Thermal stratification begins to develop in June, and the stratification is well established in July and August. During mid-summer the metalimnion is at a depth of approximately 15 meters and includes the

[1]Stewart (1961, p. 105) recognized a third water plane above the two that formed in Lake Vermont which he correlates with the Quaker Springs stage of Woodworth (1905, p. 193).

[2]MacClintock and Terasmae (1960, p. 238) have suggested that the St. Lawrence Valley was subject to subaerial weathering after lake clays were deposited, but before the deposition of marine sediments. If so, Lake Vermont drained when the Fort Covington ice dam broke and the invasion of marine waters had to await a eustatic rise in sea level.

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 or 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, as 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 in 1966 and 1967, 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 with some thoroughness, 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

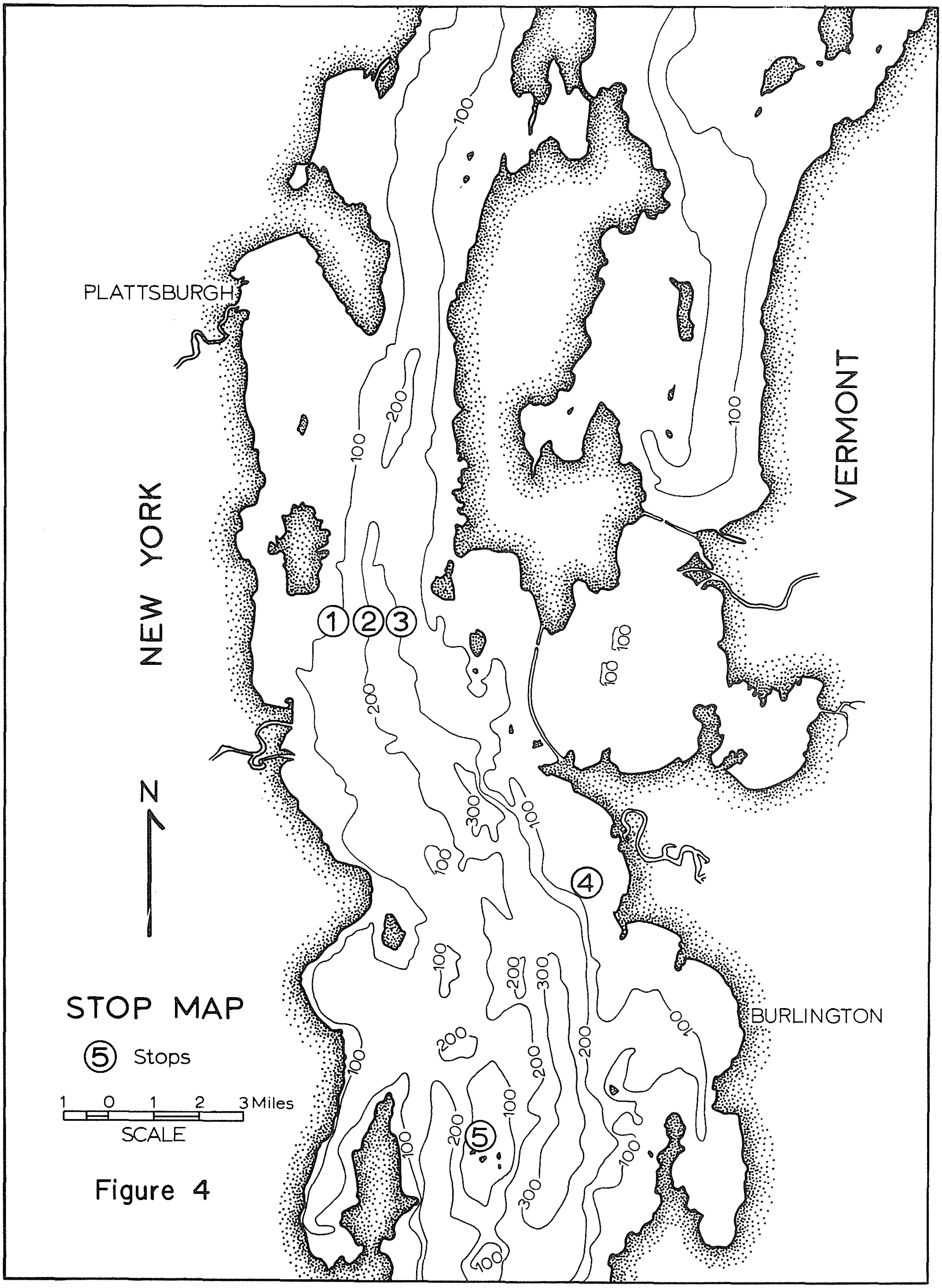
The dominant anion in the lake water is the bicarbonate ion, which is mentioned under alkalinity. A few determinations have been made of the chloride and the sulphate ions. In the main lake the median concentration of sulphate is 15.4 mg/l, and of Cl, is 5.7 mg/l. The pattern for these anions is the 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 meso-


PLATTSBURGH
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trophic 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.

SEDIMENT PROPERTIES

In 1965 a reconnaissance survey was undertaken to determine the nature of bottom sediments in Lake Champlain. This work, which is summarized here, is preliminary to future studies relating to recent sedimentation and the geological history of the lake. Grab samples have been collected (with control maintained by shore-located transits) from predetermined stations located at the intersections of a half-mile grid overlay of the lake. To date, about 1800 samples have been analyzed for grain-size distribution (Fig. 4) and sediments from selected areas have been analyzed for other properties including organic percent, clay mineralogy, light-mineral and heavy-mineral composition, percent carbonate, and several other geochemical properties.

Although the sediments show laterally gradational boundaries, they have been separated here into six general types for purposes of discussion. These six general types have been defined primarily by the physical property of grain size, although most samples within a group have other mineralogical and chemical properties in common.

Gravels

Gravel deposits make up less than 5 percent of the sediments exposed on the lake bottom. Gravels occur primarily in shallow, near-shore water and at the mouths of rivers, although gravel-sized material is also known to exist within the pebbly sandy clay deposits discussed below. At some localities the mineralogy of the gravels suggests glacial origin but at other localities, the gravels probably were formed locally from the erosion of bedrock.

Sands

Sediments defined as sands constitute about 20 percent of the lake bottom. As do the gravel deposits, the sands typically occur near shore in shallow water. They are also found at the mouths of rivers lakeward from gravel deposits. The heavy-mineral suite of the sands reflects the igneous and metamorphic terraines which outcrop on either side of the lake. Muscovite and chlorite, for example, are minerals typically found on the Vermont side; whereas, garnet, hornblende, and hypersthene characterize the heavy minerals of Lake Champlain on the New York side. The organic percent of sands (estimated through loss by ignition) is low and rarely exceeds a few percent; the carbonate percent is equally low.

Organic Muds

Muds cover about three-quarters of the lake bottom. Those which are high in organic content (5-20 percent) are referred to here as organic muds. The surface of the organic muds is a grayish brown - reddish brown hydrosol. The reduced (unexposed) sediment is dark gray in color. The organic muds are most common in deeper water (greater than 50 feet) where wave and current action are at a minimum, where fine particulate matter can accumulate, and where the oxidation of organic matter is low. Such areas occur primarily offshore, lakeward from gravel and sand deposits. Core samples have shown organic muds to be quite uniform in grain size and are generally without lamination or structures, although carbon smears and mottling do occur.

Sandy Clays

Sandy clays are found only in a few isolated areas of the lake basin today. They occur mostly on rises where erosion or non-deposition is taking place and in deeper portions of the lake basin far from shore where sedimentation rates are low. Wet, sandy clays are gray or brown to yellow-brown in color, depending upon their state of oxidation. The difference in color between the surface and the unexposed sediment is not as striking as has been found in organic muds. The water-sediment boundary is not a hydrosol and the deposit is so well-compacted that it can be penetrated with a corer only with difficulty. Sandy clays are very poorly sorted and their organic content, which averages no more than a few percent, is much lower than that found in the organic muds. An eight-food core taken on the rise north of the Four Brothers Islands penetrated clay, clay containing shale fragments, and at the bottom broken shale fragments (beneath which presumably was bedrock). Present evidence indicates that the sandy clays may be continuous with the sediments described below.

Pebbly Sandy Clays

Sediments referred to here as pebbly sandy clays have been recognized within a trough, defined approximately by the 200 foot contour interval, which follows a sinuous course along the middle of the lake from Valcour Island to the vicinity of Burlington. The sediments are extremely poorly sorted and contain material ranging from clay size to cobbles several inches in diameter. The lithology of the gravel fraction is varied and is similar to that of a glacial till. In other properties studied, the sediment resembles the sandy clays. These deposits are surrounded by organic muds which contain no gravel-sized material and virtually no sand. It does not appear likely that this sediment, or even the gravel fraction alone, could be forming today by ice or water transport from shore across the organic mud facies. This suggests that the pebbly sandy clays are not contemporaneous with the organic muds but are probably tills or ancient ice-rafted deposits.

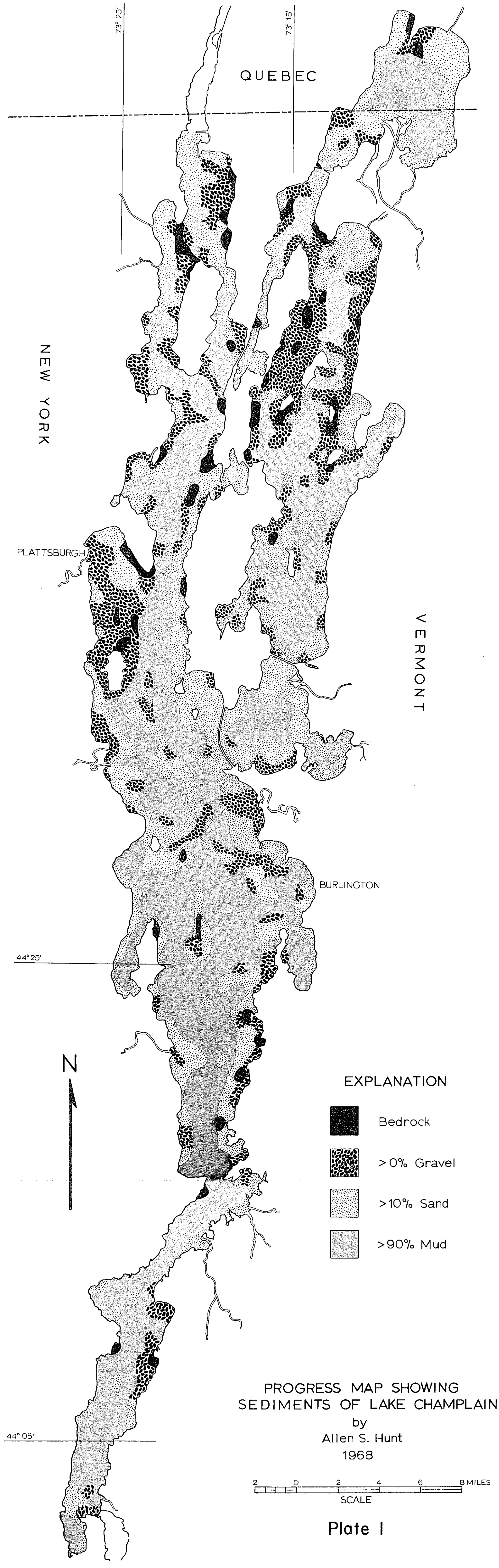
Iron-manganese Concretions

"Manganese nodules", first discovered during the 1966 field season, are now known to occur in several areas of Lake Champlain. David G. Johnson, graduate student at the University of Vermont, has been working on their origin and geochemistry. Only in the eastern part of the lake where the sedimentation rate is low are the concretions found in great concentration and with well developed concretionary structure. In other areas the concretions are mixed with a terrigenous matrix which comprises 90 percent or more of the sample. Rarely are they found at depths of more than 50 feet. At greater depths the concretions are found on slopes that adjoin shallow-water shelves. This suggests that they may have formed in shallow water and were subsequently redeposited by slumping. The shapes of the nodules range from spherical, to reniform, to discoidal. In diameter they vary from a few millimeters to greater than 10 centimeters. If well developed they reveal a concretionary structure which consists of alternating light brown and black bands, with a sand grain or rock fragment typically forming the nucleus. Chemical analysis of several dozen nodules indicates the composition to be about 10 percent manganese (MnO) with a range of 1 percent to 30 percent, and 40 percent iron (Fe_2O_3) with a range of 10 percent to 60 percent. The algae *Cladophora* sp. commonly is found attached to one surface of the concretion, indicating the orientation of the concretion on the lake bottom. Cores taken in nodule-occurring areas show that they are limited to the top 8-10 cm. of the sediment column. Scuba divers have observed a very thin veneer of silty material covering the concretions.

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 midsummer 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.



PROGRESS MAP SHOWING
SEDIMENTS OF LAKE CHAMPLAIN
by
Allen S. Hunt
1968

Plate I

Zooplankton

Muenscher (1930) conducted a survey in 1928 and enumerated 9 genera of Cladocera, 4 genera of copepods and 15 genera of rotifers. 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 relict shrimp *Pontoporeia*, small clams, and a larval chironomid.

Relict Pleistocene Fauna

The fauna of Lake Champlain includes several species that are considered to be relicts 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 Epoch, 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 been recorded from a lake in the State of Maine, but it 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 relicts. 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*.

FIELD TRIP STOPS

Stop 1. This stop, along with stops 2 and 3, will constitute a west-east traverse designed to show differences in thermal patterns, benthos, and sediment types across the lake. At stop 1, a bathythermogram will be taken to demonstrate water temperature differences with depth. A grab sample will be taken and sieved for macro-organisms, and a core sample will be collected. The sediments at this stop are organic muds which contain no gravel, less than 10 percent sand, and equal amounts of silt and clay. The mean phi size is about 8, the standard deviation 2.5 phi.

Stop 2. A bathythermogram and core will be taken and a grab sample will be sieved for benthos. The sediment at this stop is described under "sediment properties" as a pebbly sandy clay. An average sample contains 25 percent sand and gravel, 10 percent silt, and 65 percent clay. The mean grain size is 8 phi, the standard deviation 4.5 phi.

Stop 3. A bathythermogram will be taken at this station to complete the traverse profile, the benthos will be sampled, and a plankton haul will be made. Water samples will be taken from selected depths and analyzed for alkalinity, pH, and dissolved oxygen. The sediments at this stop consist of organic muds. The mean grain size is 8 phi, and the standard deviation just over 2 phi. Sand makes up less than 5 percent of the sample with silt and clay equally divided among the remaining portion.

Stop 4. This is a shallow-water stop at the mouth of the Winooski delta. Grain-size analysis has shown sediments to be about 90 percent sand, 10 percent silt, and 1 percent clay. The mean grain size is 2 phi, the standard deviation just over 1 phi. Note the absence of an interface on the sediment surface.

Stop 5. This stop is to collect sandy clay sediment. The sandy clays have much in common with the pebbly sandy clays of stop 2 in that both are poorly sorted, and both have a high percent of sand and clay with only a small percentage of silt. The pebbly sandy clay and the sandy clay may be facies of the same sediment.

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