Biogeochemistry of deep lakes in the central Alaskan Range

BIOGEOCHEMISTRY OF DEEP LAKES IN THE CENTRAL ALASKAN RANGE

jacqueline LaPerriere
Lawrence Casper

COMPLETION REPORT

Jacqueline LaPerriere
Institute of Water Resources
University of Alaska
Fairbanks, Alaska 99701

and

Lawrence Casper
Department of Chemistry
Lehigh University
Bethlehem, Pennsylvania 18015

The work upon which this completion report is based was supported by funds provided by the U.S. Department of Interior, Office of Water Research and Technology (Grant No. A-051-ALAS), as authorized under the Water Resources Research Act of 1964, Public Law 88-379, as amended.

Report No. IWR-68

February, 1976

ACKNOWLEDGEMENTS

The investigators gratefully acknowledge the cooperation of the National Park Service personnel at Mount McKinley National Park - especially the rangers stationed at Wonder Lake in 1974 and 1975, and Gary Brown, chief ranger.

Our thanks are also extended to all those who worked on this project: Frederick Payne who helped from the first effort and who contributed the subsection on vascular plants in the Results section; and Therese Payne, Donald Woodruff, Martha Kandelin, Thomas Weingartner, and Karen Stephansson.

Information provided by George Van Wyhe of the Alaska Department of Fish and Game is also gratefully acknowledged. Finally, our thanks go to Dr. Frederick C. Dean, Leader, Cooperative Park Studies Unit, University of Alaska, for his liaison efforts and encouragement.

TABLE OF CONTENTS

LIST OF FIGURES

TABLE

INTRODUCTION

Many limnological projects are conceived when the limnologist first sees a lake and becomes inspired. This project had its beginning when Lawrence Casper, one of the investigators, was a guest of the National Park Service as a weekend camper at the Wonder Lake Campground within Mount McKinley National Park. On the next visit to this campground for the same purpose, Mr. Casper took along several pieces of equipment for making simple limnological measurements. On this trip, he was accompanied by Frederick Payne, a graduate student from Michigan State University, who was in Alaska working with aquatic plant community structure. Following this visit to the lake, a research project proposal was drawn up for the purpose of obtaining funds in order to study several limnological aspects of this lake and others related to it.

The relative high importance of vascular aquatic plant production in the Arctic had been noticed by John Hobbie (1973). In an intensive study of a deep subarctic lake, Harding Lake, being conducted by the Institute of Water Resources, University of Alaska, the relative high importance of rooted aquatic plants had also been noted. Thus, a question arose as to whether or not the primary production of vascular aquatic plants is higher than that of phytoplankton in subarctic lakes as is the case in arctic lakes which usually have higher biomass concentrations of algae than subarctic lakes (Hobbie, 1973).

The stated objectives of this project were:

1) To conduct a biogeochemical reconnaissance of selected deep subarctic lakes in the central Alaska Range.
2) To develop hypotheses concerning the regional limnology.
3) To collect biological specimens to extend knowledge of taxonomic distributions, especially of aquatic plants and phytoplankton.
4) To estimate the seasonal nutrient budget for these lakes.

While many of these objectives were fulfilled by this study, it has become evident that more intensive study will be necessary to fulfill all of these objectives. There is a National Park Service Regulation prohibiting the landing of small aircraft within Mt. McKinley National Park, therefore a planned late winter or early spring run to the lake had to be cancelled since alternate entry by sled could not be arranged. This time of year may be the time of peak algal primary productivity as has been found in other subarctic and arctic studies. Sampling at this time of year, though difficult, is highly recommended for future studies.

DESCRIPTION OF LAKE BASINS

Wonder Lake is located at 63° 28' North latitude and 150° 52' West longitude in Mt. McKinley National Park, 27 miles NNE of Mt. McKinley in the foothills of the Kuskokwim basin. Lying at an elevation of 610 m (Figure 1), it is contained in a deep, steeply sided valley which is lateral to the glacially fed McKinley River. The dam at the southern end of the lake is of glacial origin with boulder fields extending over the southern portion of the moraine.

The lake is of the long narrow form characteristic of a flooded valley, with a length of 4.98 km and an average width of 0.53 km. As can be seen in Figure 2, the southern tip of the lake has been partially isolated by a submerged bar. This pond-like region was found to be the most productive area of the lake for vascular hydrophytes. The morphology of the lake approximates an inverted truncated pyramid, providing very little littoral area in the lake.

Except for limited drainage from the slopes surrounding the lake, inflow to the lake is from a small drainage to the east. However, an outlet from the lake is only about a hundred meters from the inflow, so much of the flow may be short-circuited through the adjacent littoral area and, as a result, probably has negligible effect on the lake.

Paxson Lake, elevation 793 m, lies at 62° 55' North latitute and 145° 32' West longitude on the southern slope of the Alaska Range in the Copper River Basin (Figure 1). This lake receives most of its inflow from the Gulkana River which has its origin several miles north at Summit Lake and which also flows out from the lake at its southern end.

Van Wyhe and Peck (1964) describe the formation of Paxson Lake and its sister lake, Summit, by morainic damming during the Pleistocene glaciation. The outlet from Paxson Lake was not visited by us, but the potential for the lake to act as a sediment trap is very evident. The approximately fifteen miles of the Gulkana River from Summit Lake to Paxson Lake cuts deeply through morainic material and the river enters carrying much sediment.

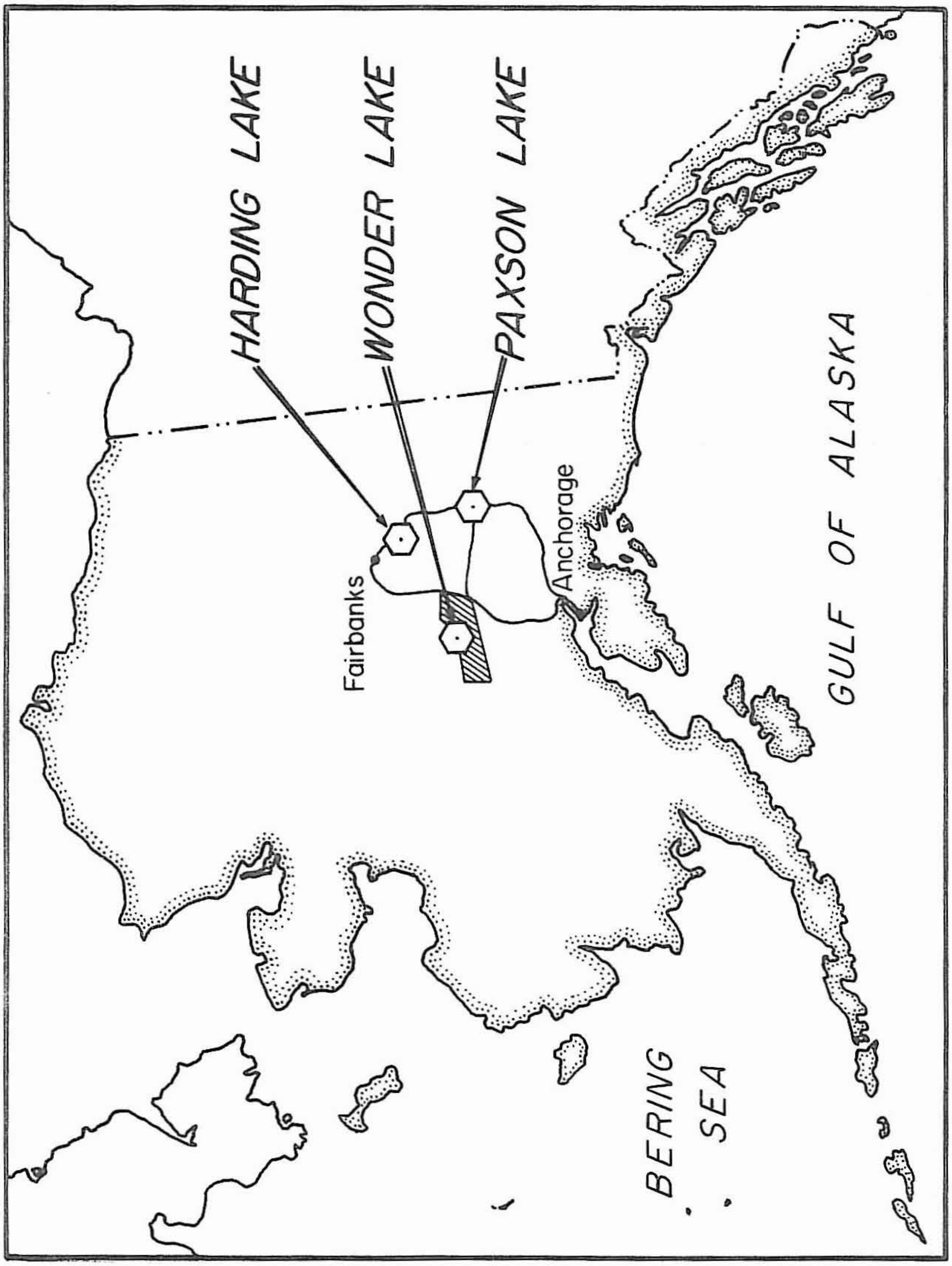

Figure 1: Location of Study Lakes, Paxson and Wonder, and the Reference Lake, Harding Lake.

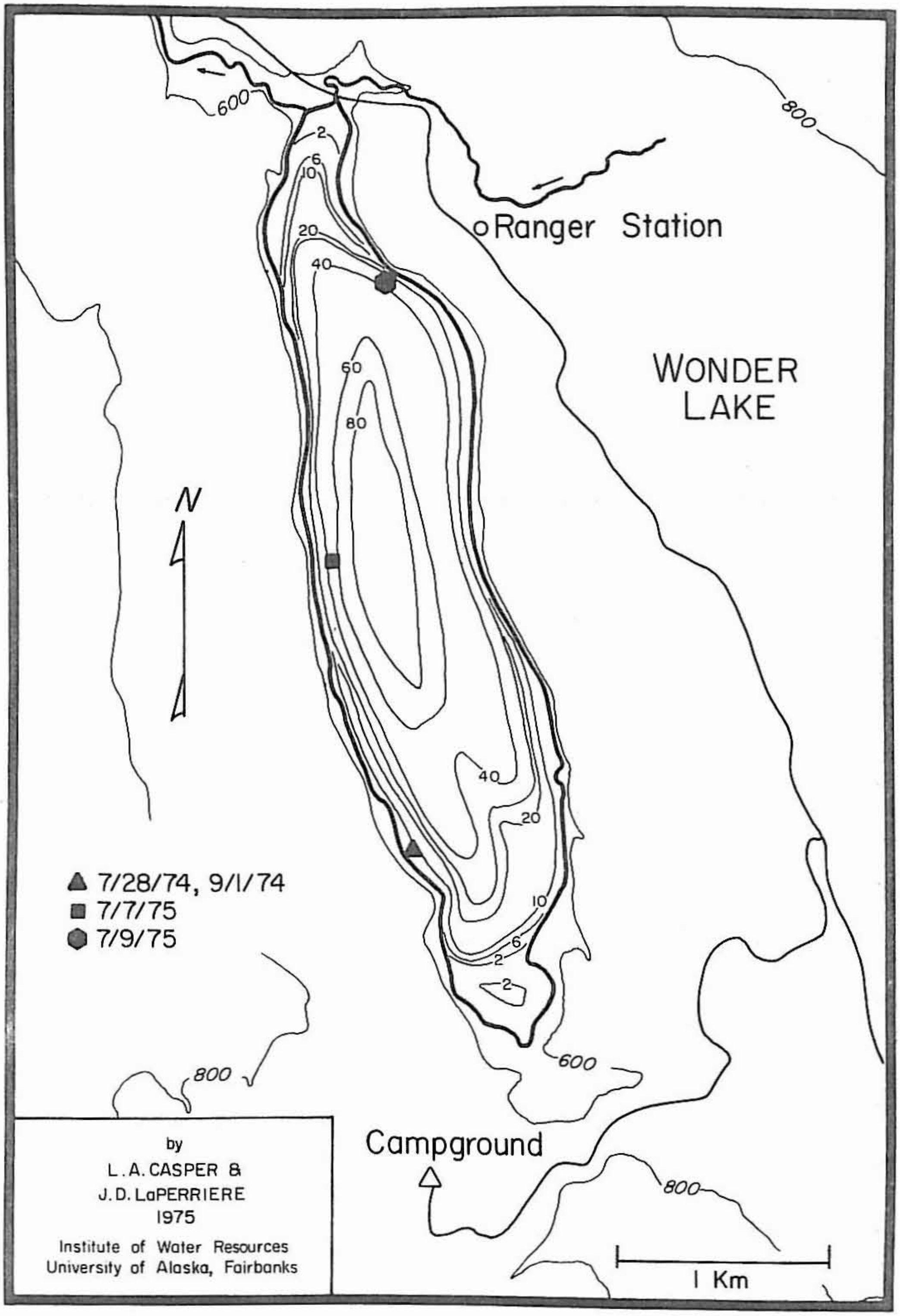

Figure 2: Morphometric Map. Wonder Lake, Alaska with Approximate Station Locations.

The climatic conditions of the two lake areas are not dissimilar. A mean annual temperature of about -2.2°C with an annual variation of ±18°C for Paxson Lake and a smaller variation of ±14°C for Wonder Lake is only slightly higher than the temperatures characteristic of lake basins in the Tanana Valley of interior Alaska. Because of the similarities of the thermal climates in the lake basins, differences in lake thermal characteristics must be attributable to hydromechanics.

Precipitation for the two lakes is near 40 cm per annum. However, the lake basin hydrology is significantly different for the lakes: Wonder Lake has only one small defined inlet and outlet, whereas Paxson Lake is shallower and has a significant flow along the axis of the lake.

METHODS

Basin Morphometry

Wonder Lake was morphometrically (bathymetrically) mapped by means of an electronic depth sounder sensitive to 100 m. Transects were set by dead reckoning and soundings were taken at selected time intervals. A uniform speed was maintained along each transect by means of a battery-driven electric outboard motor. There were no winds noted during the mapping operation.

Soundings were placed along the transects as drawn across the outline of the lake, obtained by enlarging a U.S.G.S. topographic map. The number of time divisions for each transect were stepped off with dividers and the soundings were entered. Contours were then drawn by eye (Figure 2). A hypsometric graph of the lake is presented in Figure 3.

The map of Paxson Lake was obtained from an Alaska Department of Fish and Game publication (Van Wyhe and Peck, 1968). (Figure 4).

Figure 5 presents a hypsometric graph of this lake.

Temperature, pH, Depth, Electrical Conductivity, and Dissolved Oxygen

Depth profiles of the lakes for temperature, electrical conductivity, dissolved oxygen, and pH were measured with a Martek Mark II Water Quality Monitoring System. This unit includes a transducer package which is connected to the readout unit by a 46 m submersible cable.

The sensor package includes a thermistor temperature transducer, a diffused silicon diaphragm pressure (depth) transducer, a platinized conductivity cell, pressure-equalized thermally compensated polargraphic oxygen electrode with a vibrating-wand stirring mechanism, and a sealed glass pressure-equalized Ag-AgCl pH cell which is thermally compensated. The pH assembly also includes a pre-amplifier unit for transmission of the signal.

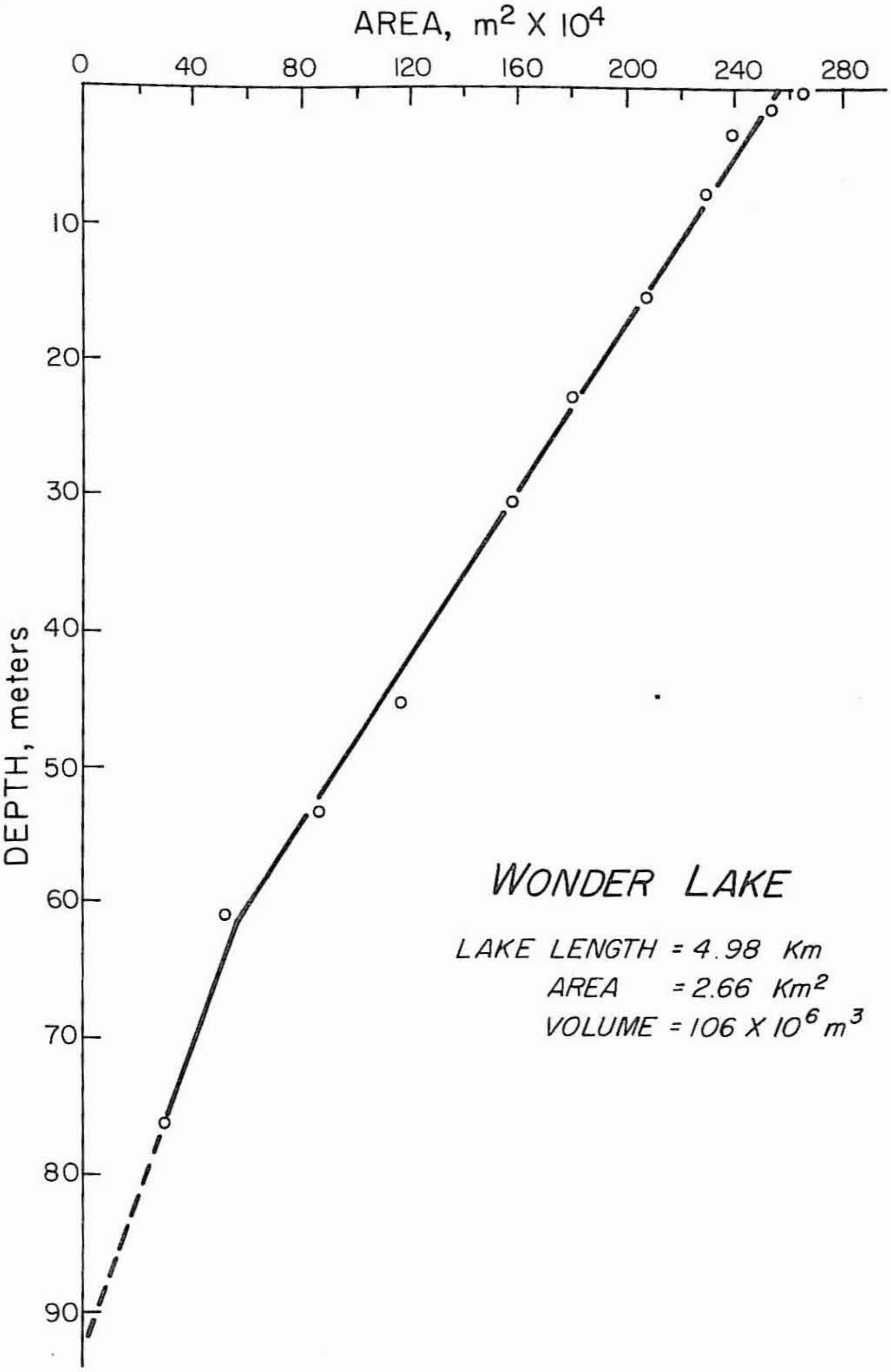

Figure 3: Hypsometric Graph. Wonder Lake.

]]>

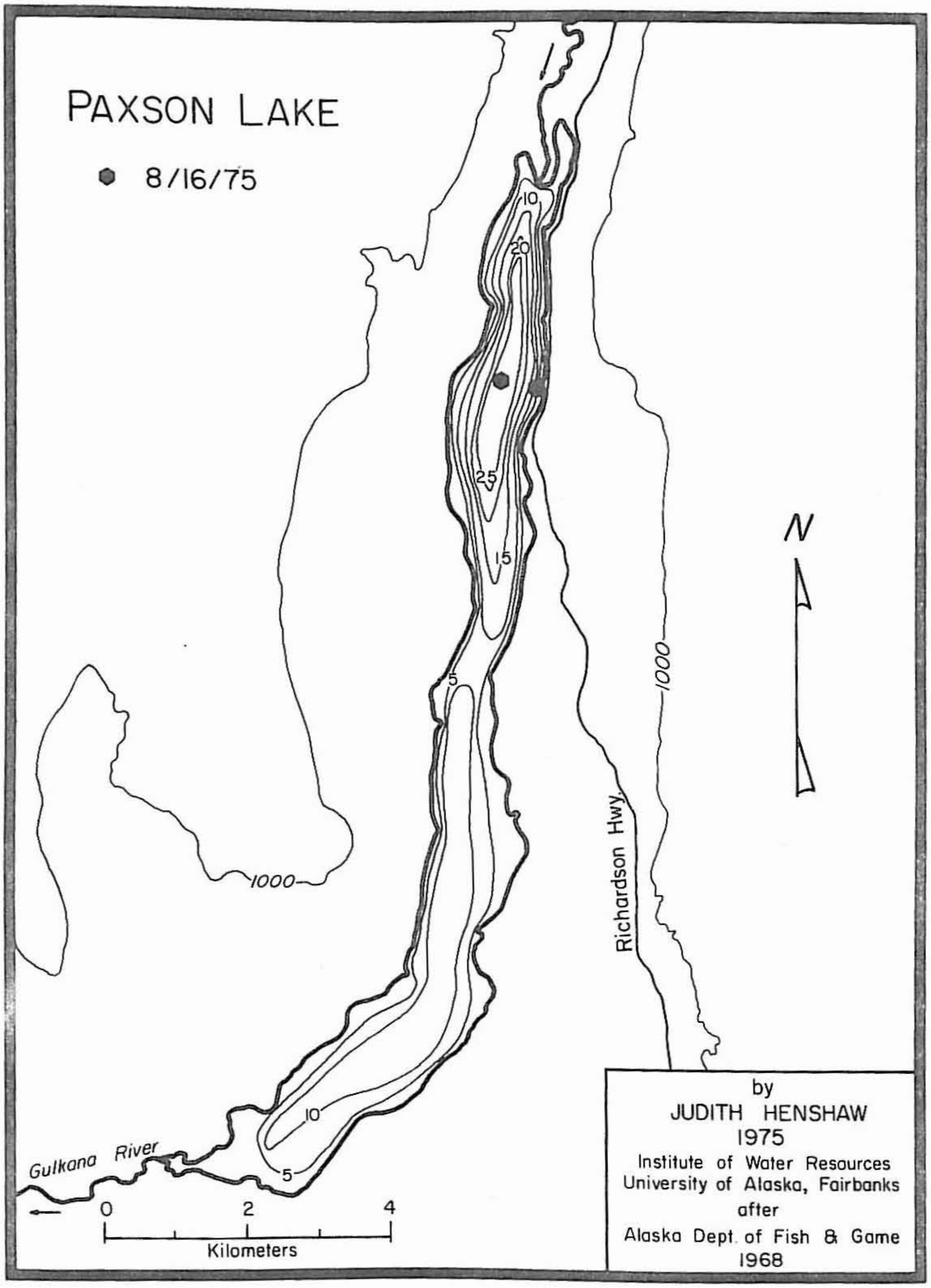

Figure 4: Morphometric Map. Paxson Lake, Alaska with Approximate Station Locations.

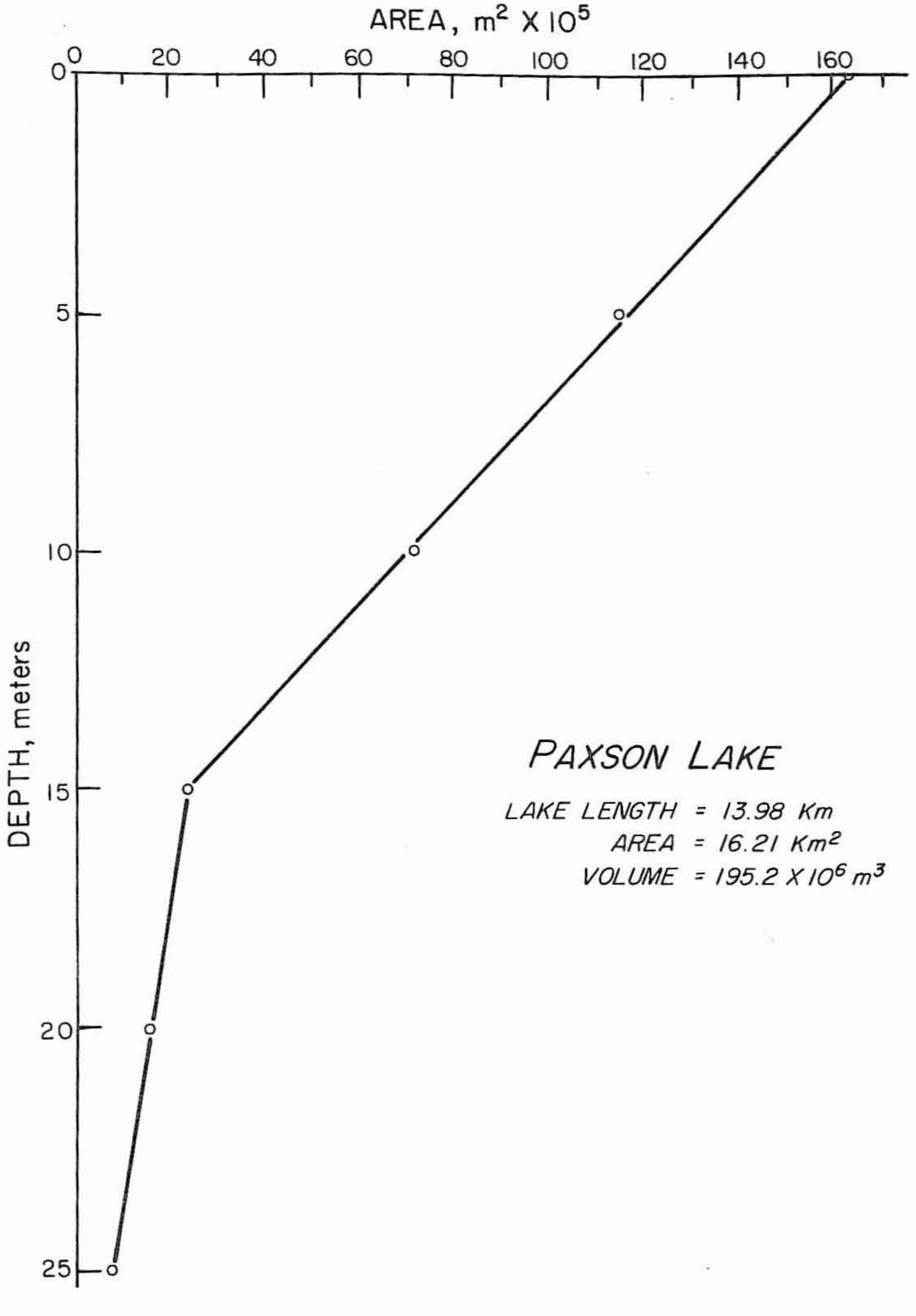

Figure 5: Hypsometric Graph. Paxson Lake.

The readout unit is operated by an internal battery and is completely portable. The outputs are read on 3½-inch taut-band meters with mirrored scales and knife-edge pointers which give a maximum of stability under pitch and roll. Range switches on all variables except temperature allow measurement to a fairly high degree of accuracy.

Profiles were run at stations selected by sighting to landmarks from the boat and marked with buoys. The sensors were allowed to remain at each depth for several minutes to equilibrate before the output was recorded.

The dissolved oxygen meter was calibrated in the field by the temperature-saturation method. This meter was not functioning during the Paxson Lake run.

The pH meter has an expanded scale function which allows very accurate measurement of this variable. The calibration functions include zero, assymetry, and slope which allow the calibration and span to be set accurately. The calibration procedure is usually conducted in the laboratory prior to a field run as the subunit is extremely stable and may be used for long periods without recalibration, as frequent checks with buffer standards will confirm. As indicated above, the pH probe is temperature-compensated, allowing accurate measurement through the thermocline area without extensive equilibration time. The stability of the pH readout is due, in part, to the preamplifier which reduces noise through conversion of the high-impedance pH signal to a low-impedance transmission signal.

Temperature measurement was somewhat inaccurate since the readout meter is not provided with range scales. The meter range of 0 to 40°C allows only crude estimation to 0.1°C.

Alkalinity

Alkalinity, a measurement of non-radioactive carbon (C-12) available in the natural system, was measured by titration with 0.02N HCl to an endpoint determined by monitoring pH with a field pH meter and simultaneously monitoring electroconductivity with a conductivity bridge according to the method presented in the IBP manual on chemical methods (Golterman, ed. 1971).

Algal C-14 Productivity

Algal primary productivity was measured by incubating 125-150 ml water samples innoculated with 5 μCi of $NaHCO_3$ *in situ* for twenty-four hours. The samples were taken with a PVC Van Dorn sampler and distributed to two light bottles and one dark bottle for each depth. The dark bottles were prepared by dipping the typical borosilicate reagent bottles also used as light bottles in black latex and taping with two layers of black electrical tape. Aluminum foil was used to cover the stopper and neck of the dark bottles.

The bottles were secured on their sides in plexiglass holders along a buoyed and anchored cord. At the end of the incubation period, each bottle was placed in an insulated light-tight box and filtration of either the whole bottle or a 50 ml aliquot through a 2.5 cm diameter 0.45 μm membrane filter was conducted as quickly as possible.

Filtration was controlled at 15-20 cm of mercury to prevent lysis of cells. The filters were not dried but were immediately dropped into 10 ml of Aquasol®, a liquid scintillation cocktail which dissolves the filter and which is miscible with water. Drying was not conducted in order to prevent autorespiration of tagged cell material which could happen with slow death of the algae.*

Counting was conducted in an ambient temperature liquid scintillation counter for 10 minutes on each vial containing a filter. Corrections were made for background and quench.

Light Penetration

At Wonder Lake, light penetration was measured with a G. M. Manufacturing Company Model 268 WA300 submarine photometer with matched Weston photocells encased under opal glass filters in a gimballed deck cell and a finned sea

---

*R. T. Law, 1974: personal communication.

cell. The penetration of red, blue, and green light was measured by attaching the appropriate colored filters over the opal glass filter on the sea cell.

Secchi depths were also taken using a 50 cm oceanographic type Secchi disk.

Chlorophyll *a* and Phaeopigments

Chlorophyll *a* content of the algae was determined according to the method delineated by Strickland and Parsons (1965). Two liters of water were filtered through a glass fiber filter under reduced light conditions and the filters were frozen until the extraction could be carried out. Phaeopigments were determined according to the method and calculations recommended by the IBP manual on chemical methods (Golterman, 1969).

Vascular Plants

Vascular aquatic plant colonies in Wonder Lake were observed and sampled by a plant scientist equipped for skin diving. Production estimates were made using a method closely paralleling that presented by D. F. Westlake in the IBP "Manual on Methods for Measuring Primary Production in Aquatic Environments" (Vollenweider, ed., 1969).

Quadrat sampling was conducted with the roots left connected to the plants. The plants were returned to the laboratory where dry weight was measured and the plants were frozen for subsequent ash-free dry weight measurements.

An attempt was made during July of 1975 to measure vascular plant productivity at Wonder Lake, using a light-dark bottle technique and measuring changes in dissolved oxygen. While some rough estimate of production rate could probably be made from the data obtained, the extreme variability between replicates emphasized the recommendations of R. G. Wetzel (1964) that this technique be replaced by his more accurate one.

Nutrient Chemistry

Samples for plant nutrient concentration analyses were taken with a 6.1 PVC Van Dorn sampler and distributed to small labeled polyethylene bottles. One bottle was prepared for each nutrient analysis planned. These samples were immediately frozen and carried to the laboratory in insulated boxes or, in the case of Paxson Lake, rushed to the laboratory for immediate analysis or freezing.

Nitrate and nitrite nitrogen were measured together colorimetrically as nitrite by the sulfanilimide method after reduction of the nitrate to nitrite on a cadmium wire coil amalgamated with mercuric chloride. The method closely follows that of M. P. Stainton (1974) utilizing an Auto-Analyzer. The charging of the reduction coil, however, was conducted according to the recommendations of Dr. Robert C. Clasby* with 10 ml of distilled/deionized water alternated with 10 ml of 10% HCl, 10 ml of 2% $HgCl_2$, and 10 ml of EDTA, beginning and ending with the water rinse.

Total phosphorous was measured utilizing a hand digestion with ammonium persulfate and sulfuric acid followed by the standard colorimetric orthophosphate analysis as ammonium phosphomolybdate. An Auto-Analyzer was used and the method follows that recommended by USEPA (1974).

Zooplankton

Zooplankton samples were taken (at Paxson Lake) by 20 m vertical hauls with a small (76 cm x 13 cm mouth diameter) Wisconsin net which has a mesh size of 76 microns. The samples were washed into 20 ml vials with 90% ethanol. Upon return to the laboratory, these vials were emptied into tared weighing pans and dried in a 60°C oven for 24 hours to constant weight.

---

*1975: personal communication.

RESULTS

Thermal Regime

The thermal characteristics of Wonder and Paxson Lakes are very dissimilar. The temperature characteristics of these lakes are shown in Figures 6 and 7. Van Wyhe and Peck (1964) report additional temperature profiles for Paxson.

The isotherms for Wonder Lake resemble summer stratification curves for a deep, temperate lake but two of the curves appear to have secondary thermoclines. Hutchinson (1957) points out that multiple thermoclines are likely to be formed by solar heating to form a thermocline followed by cooling due to weather changes. Such extreme variation has been observed at this lake, with clear, hot days followed by cold rain or cool winds fetching along the length of the lake.

Although the lake was not observed during the vernal or autumnal periods, it is very similar in its summer thermal characteristics to Harding Lake (unpublished data) as well as its climatic and other physical parameters, that it is reasonable to assume the lakes follow similar annual cycles. That is to say, there exists the possiblity of negligible vernal circulation due to a late breakup with extensive under-ice warming, but with complete autumnal mixing due to winds.

The heat budget for Wonder Lake can be calculated only for the summer period, for which a value of 8800 cal/cm^2 was found. This is compared to the value of 8700 cal/cm^2 for the summer heat budget calculated for Harding Lake, another deep, subarctic lake.

Breakup of the ice on Wonder Lake occurs in late May or early June. It is likely that the ice cover is a significant factor in the annual heat budget as was the case for Harding where the winter heat budget (1972-1973) was calculated to be an *additional* 8700 cal/cm^2, largely due to a very thick ice cover. The fact that mean annual snowfall for Wonder Lake is about 250 cm, about double that for Harding, may lower this somewhat due to insulation.

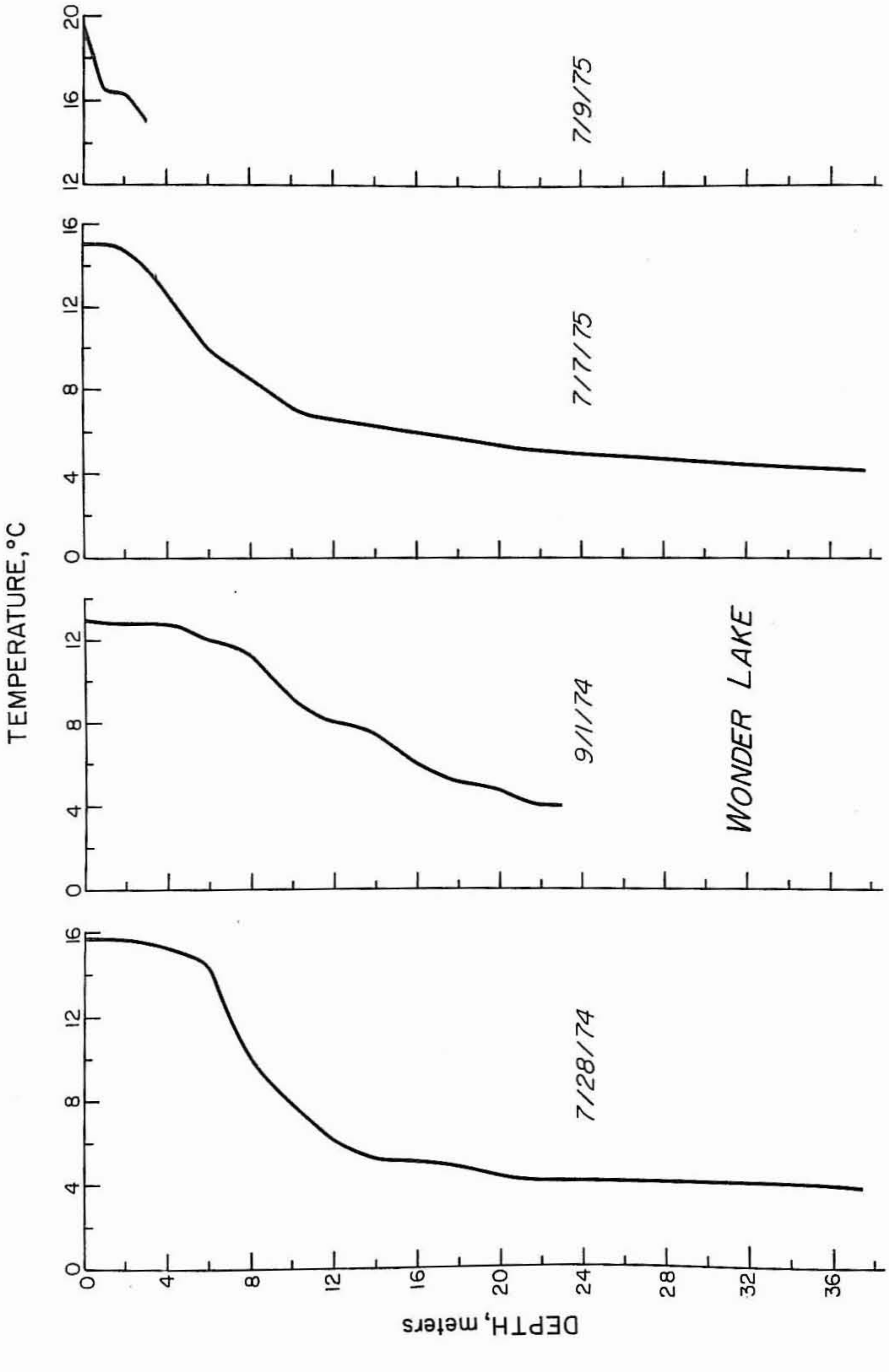

Figure 6: Temperature Profile. Wonder Lake.

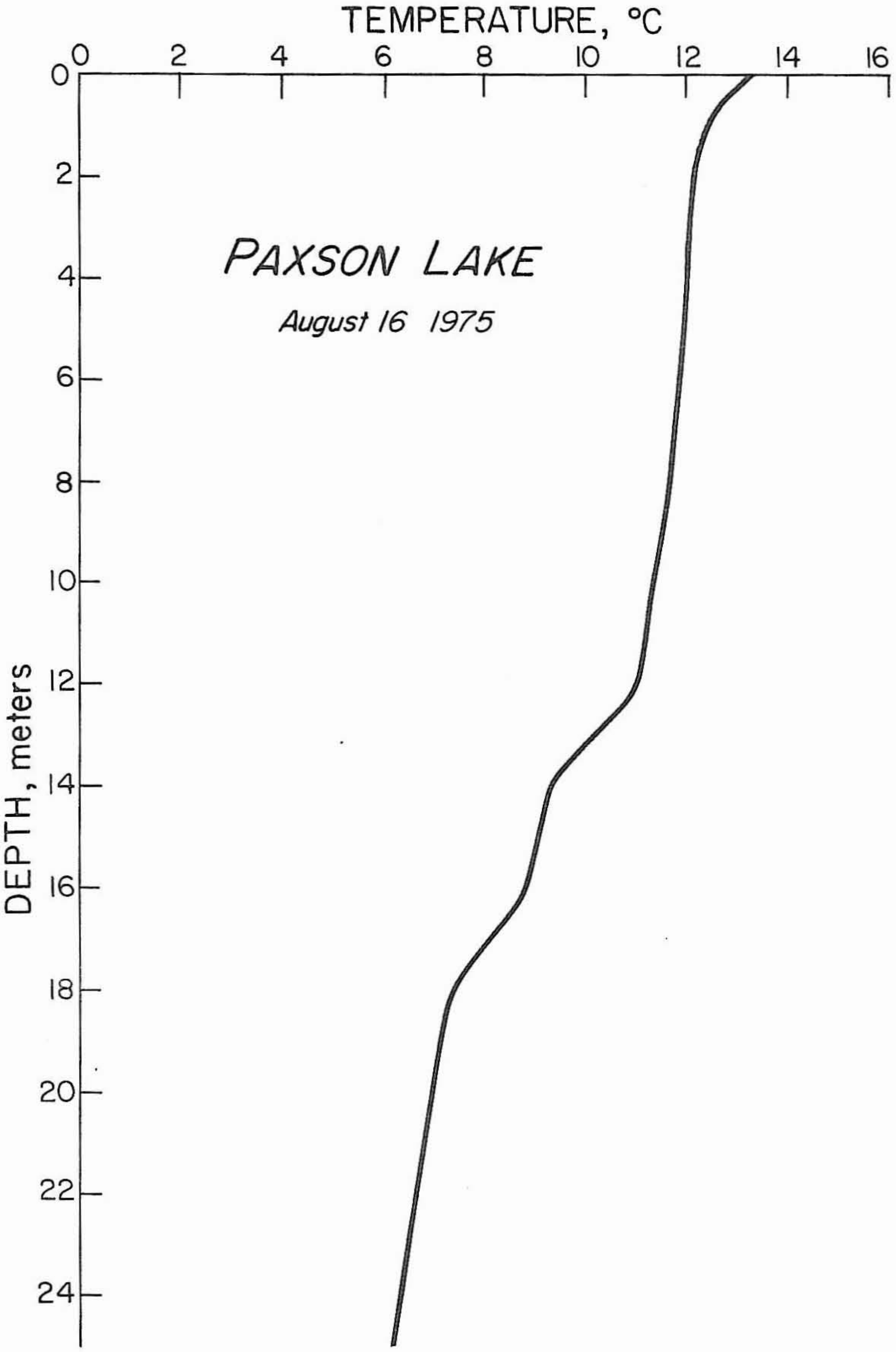

Figure 7: Temperature Profile. Paxson Lake.

The temperature profile of Paxson Lake shows stratification with a rather broad region of temperature change. Vestiges of a double thermocline are apparent in the profile. Van Wyhe and Peck (1964) report several temperature profiles taken over a 6-week period in the summer which show little evidence of stratification. The temperature measurements taken during 1975 are about 2°C warmer for the upper 10 meters than those reported by Van Wyhe and Peck. This significant extra heating may have been a result of an unusually warm, clear summer in central Alaska in 1975.

Paxson Lake lies in a long, narrow valley which leads to a pass in the mountains to the north. Winds frequently fetch along the axis of the lake. In concert with the large inflow of the Gulkana River, wind-mixing may have been sufficient to prevent stratification during the period studied by Van Wyhe and Peck. The stratification observed in 1975 may be anomalous due to the unusual weather conditions of that period.

The summer heat budget calculated for Paxson Lake based on the 1975 data is 13,600 cal/cm^2. This higher figure is reasonable when inflow and mixing are taken into account. Hutchinson (1957) points out that wind fetching along the axis of a lake can raise the hypolimnion sufficiently close to the surface to render heat transfer more efficient.

Oxygen

Figures 8 and 9 show the distribution of dissolved oxygen in Wonder Lake to be orthograde, that is, mainly the result of physical effects and relatively unaffected by biological processes.

There are a few reasonable explanations for the depletion of dissolved oxygen below 30 meters measured on July 7, 1975. Unfortunately, the cord for the Martek multiprobe system restricted us to measurements in the upper 40 m of water and further measurements to investigate this phenomenon were not taken. The station at which this profile was taken was approximately 40-50 m deep, depending on drift of the boat from the anchored buoy. Although the thickness of the bottom sediments at this station is unknown, it is probable

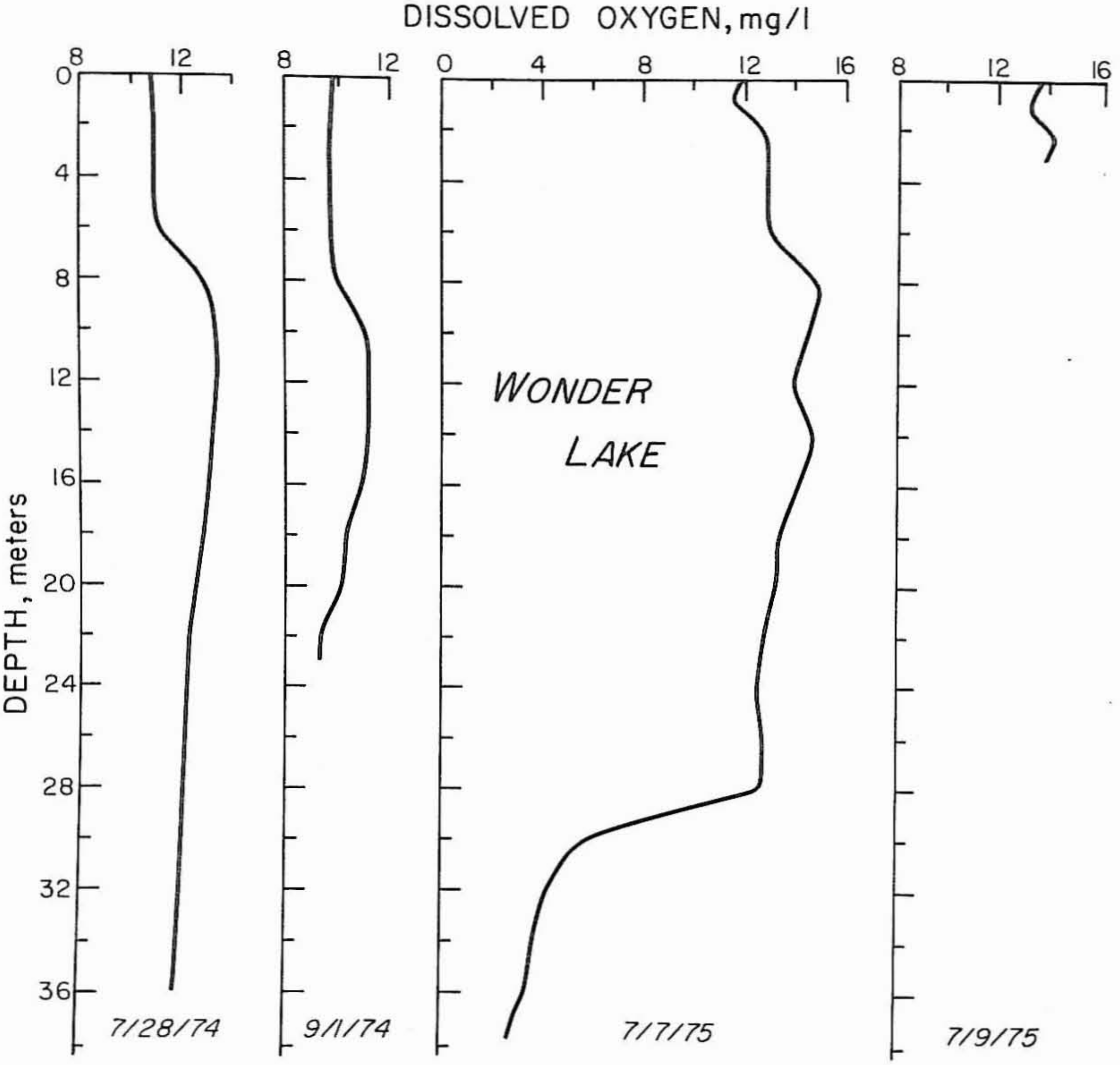

Figure 8: Dissolved Oxygen Profiles. Wonder Lake.

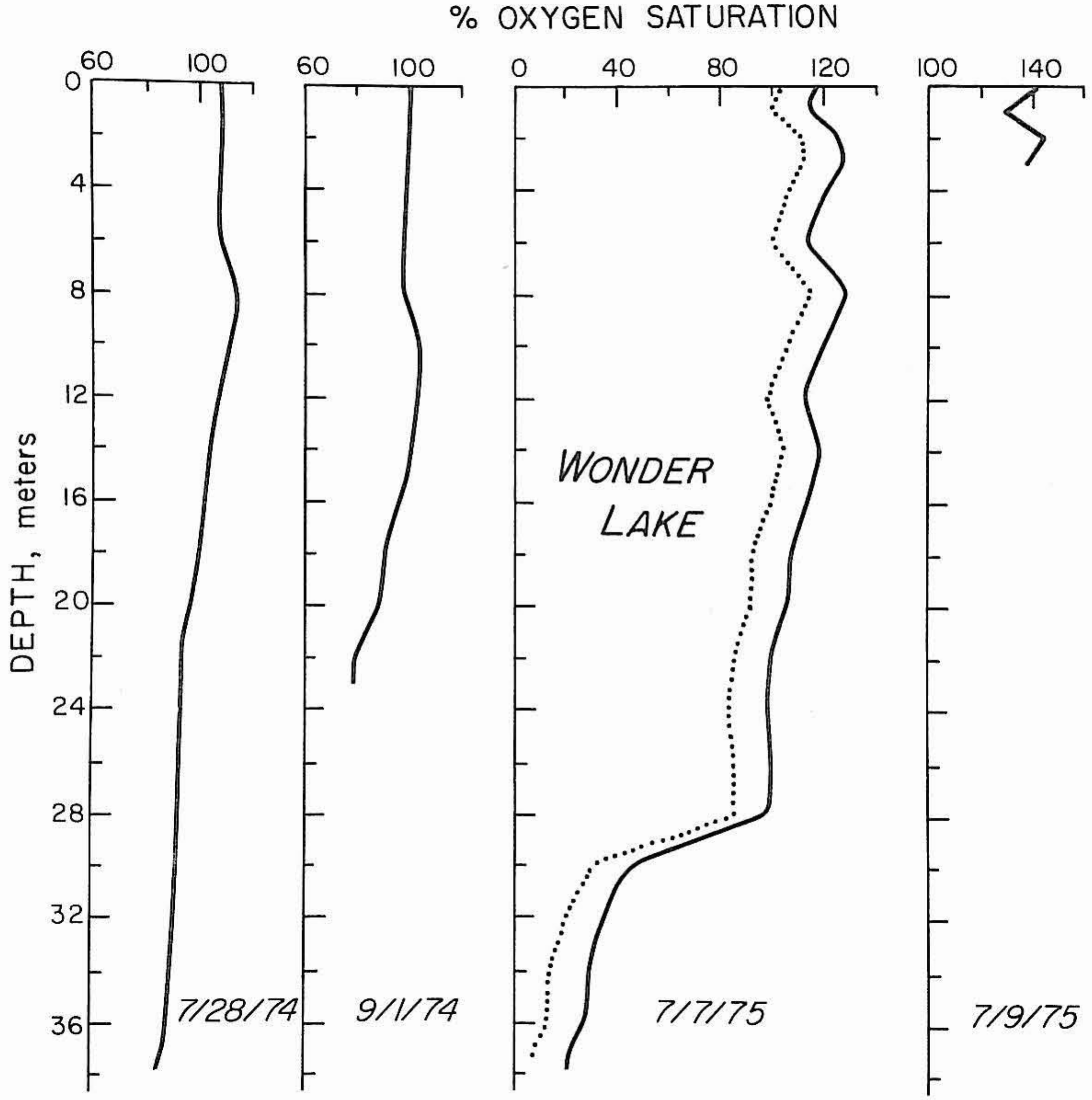

Figure 9: Oxygen Saturation Profiles. Wonder Lake.

that the probes were sinking toward and then through a mud and water mixture that is several meters thick. This type of sediment has been observed in the depths of Harding Lake by scuba divers who were able to penetrate several meters feet-first using swimming motions.

The oxygen depletion effect may have been accentuated by or caused entirely by groundwater inflow as groundwater usually contains relatively small amounts of dissolved oxygen.* Finally, monomixis, or lack of a complete vernal circulation, may actually be shown by this profile.

While the actual dissolved oxygen measurements taken on July 7, 1975, are plotted in Figure 8, Figure 9 depicting oxygen saturation also contains a parallel dotted-line plot wherein the values near the top of the water column are set to vary around 100% saturation. This may be justified by the fact that, although the oxygen probe was carefully calibrated by saturating a bucket of water of known temperature and adjusting the meter, chemical calibrations were not carried out at this time and the pressure diaphragm on this probe failed entirely a few weeks later. This type of adjustment may also be justified for the profile measured July 9, 1975, at the shallow station, but some supersaturation may be expected as this profile was taken late on a bright, clear morning after a clear, cool night.

Algal C-14 Productivity

The algal primary productivity measurements taken at Wonder Lake are shown in Figure 10. The relatively higher productivity of the September measurement is supported by a similar phenomenon at Harding Lake (unpublished data). The erratic profile of July 5-6, 1975 cannot be attributed to experimental error or determinate error and so is puzzling. This could likely be due to the interaction between the abiotic and biotic components of the system, or to interrelationships between the plankters. This latter is a likely explanation as, at 4 m at the shallow station, the dark bottle value was

---

*W. S. Reeburg, 1975: personal communication.

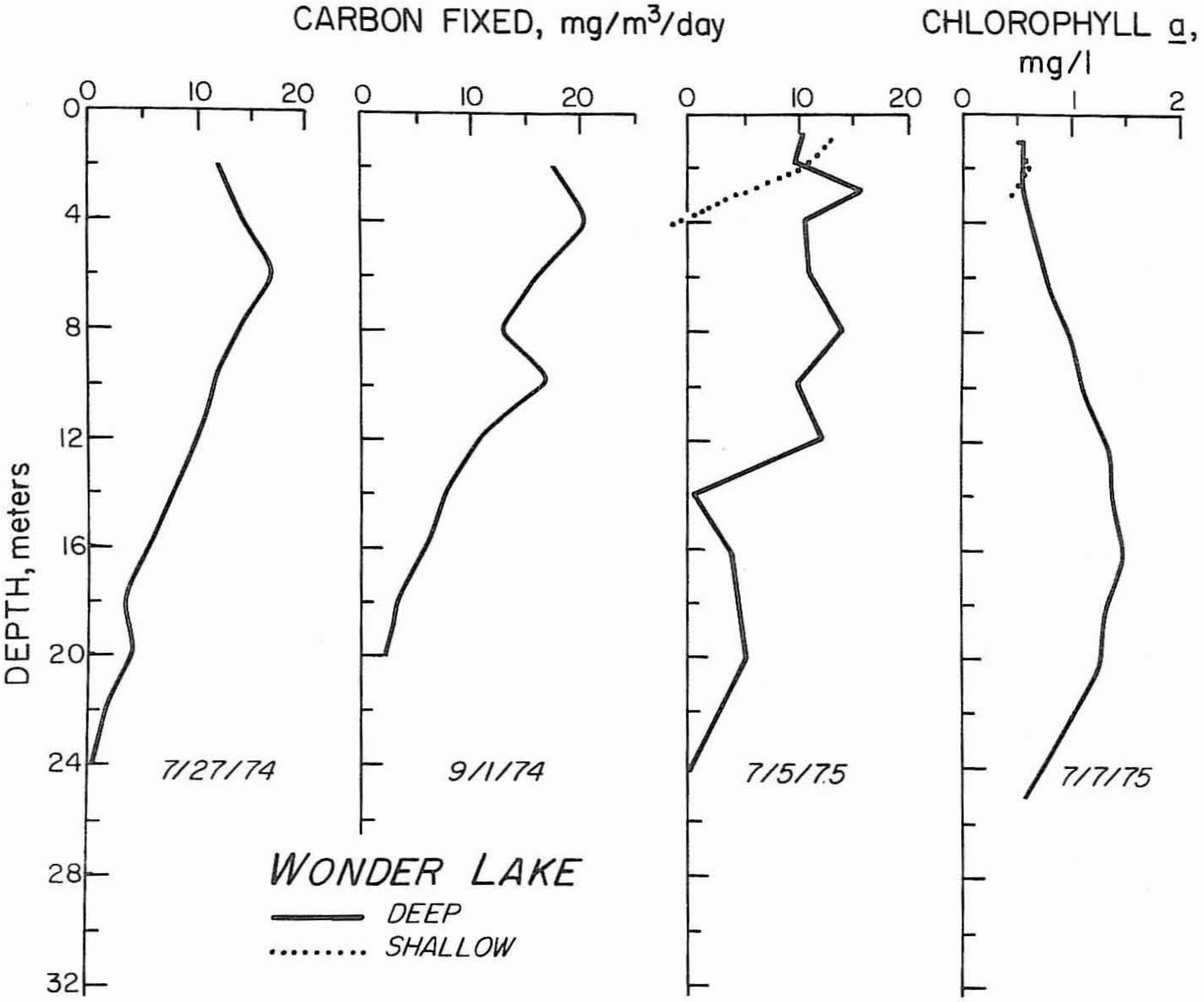

Figure 10: Algal Growth Parameters. Wonder Lake.

higher than the light bottle average. This sometimes takes place when zooplankton are not screened from the water placed in the bottles (Dugdale and Wallace, 1960).

Peak productivity at Paxson Lake is noted to be higher than that ever measured at Wonder Lake. However, productivity in this range has been measured at Harding Lake under the ice in late spring. The integral primary productivity for the entire water column is comparable between the two lakes: 188 ± 13 mg/m^2/day for Wonder Lake and 107 mg/m^2/day for Paxson Lake due to the rapid drop-off in productivity below about 8 m in Paxson Lake. This is obviously due to light attenuation differences with photosynthetically important light penetration deeper in the clearer waters of Wonder Lake. See Figure 11.

Light Penetration

Light penetration data presented in Figure 12 is typical of a lake containing small amounts of dissolved oxygen matter (Hutchinson, 1957), that is, most transmissive in the green rather than in the blue which is the case for pure water, or in the orange and red as in the case of high amounts of dissolved coloring material. The Secchi depth was 11.0 m.

Neither of these types of measurements were conducted at Paxson Lake due to a lack of proper weather conditions for Secchi readings and to a broken opal glass filter on the sea cell of the submarine photometer. However, Alaska Department of Fish and Game personnel in their study (Van Wyhe and Peck, 1964) measured Secchi depth routinely with a 20 cm Secchi Disk and their measurements averaged about 4 meters.

Chlorophyll *a* and Phaeopigments

Chlorophyll *a* profiles, as illustrated in Figures 10 and 11, show an even distribution through the water column at Paxson Lake in August, 1975, but, at Wonder Lake in July, there was some increase in concentration to a peak of 16 m. This may be due to algae adapted to a low light level, and which may

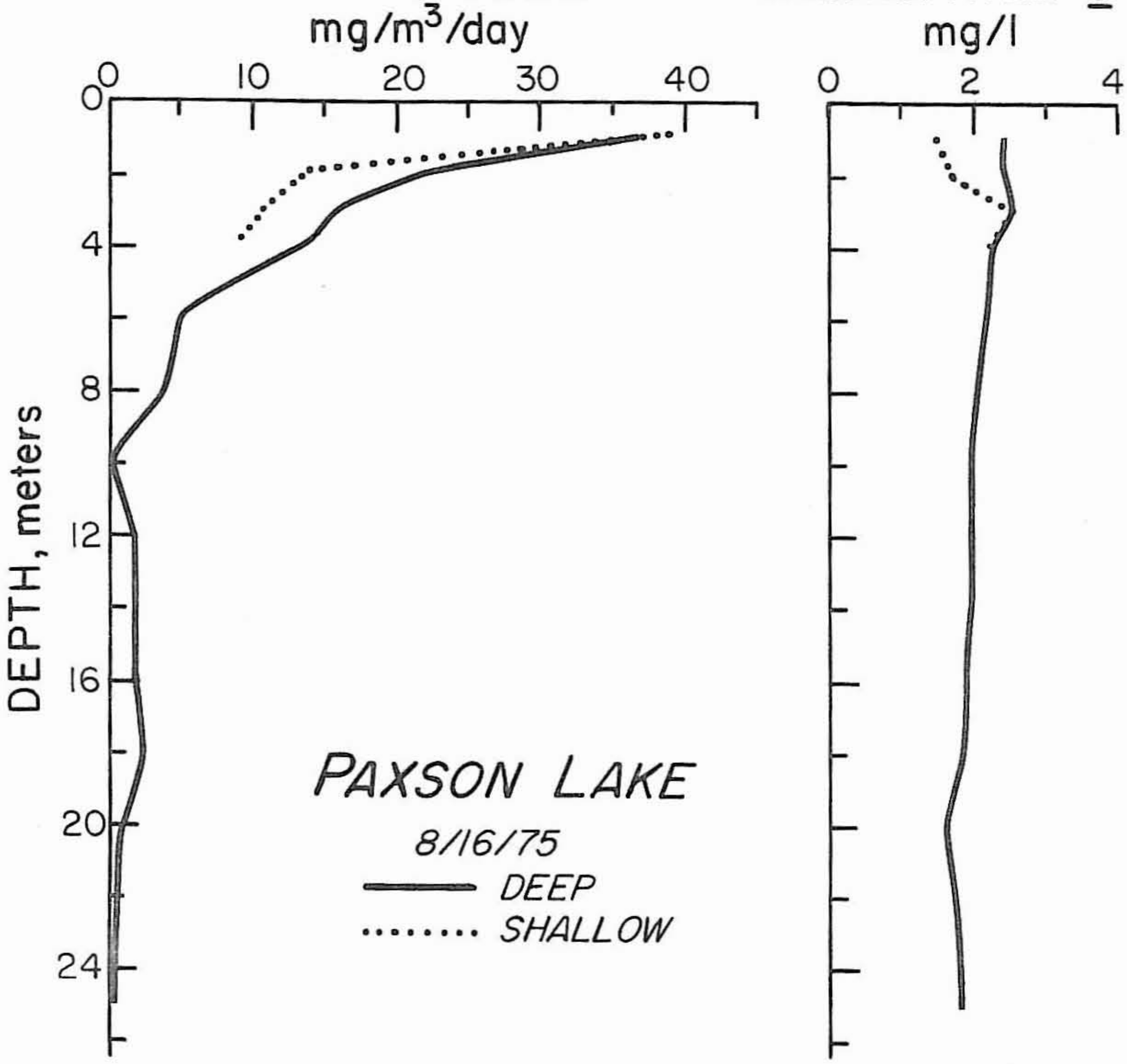

Figure 11: Algal Growth Parameters. Paxson Lake.

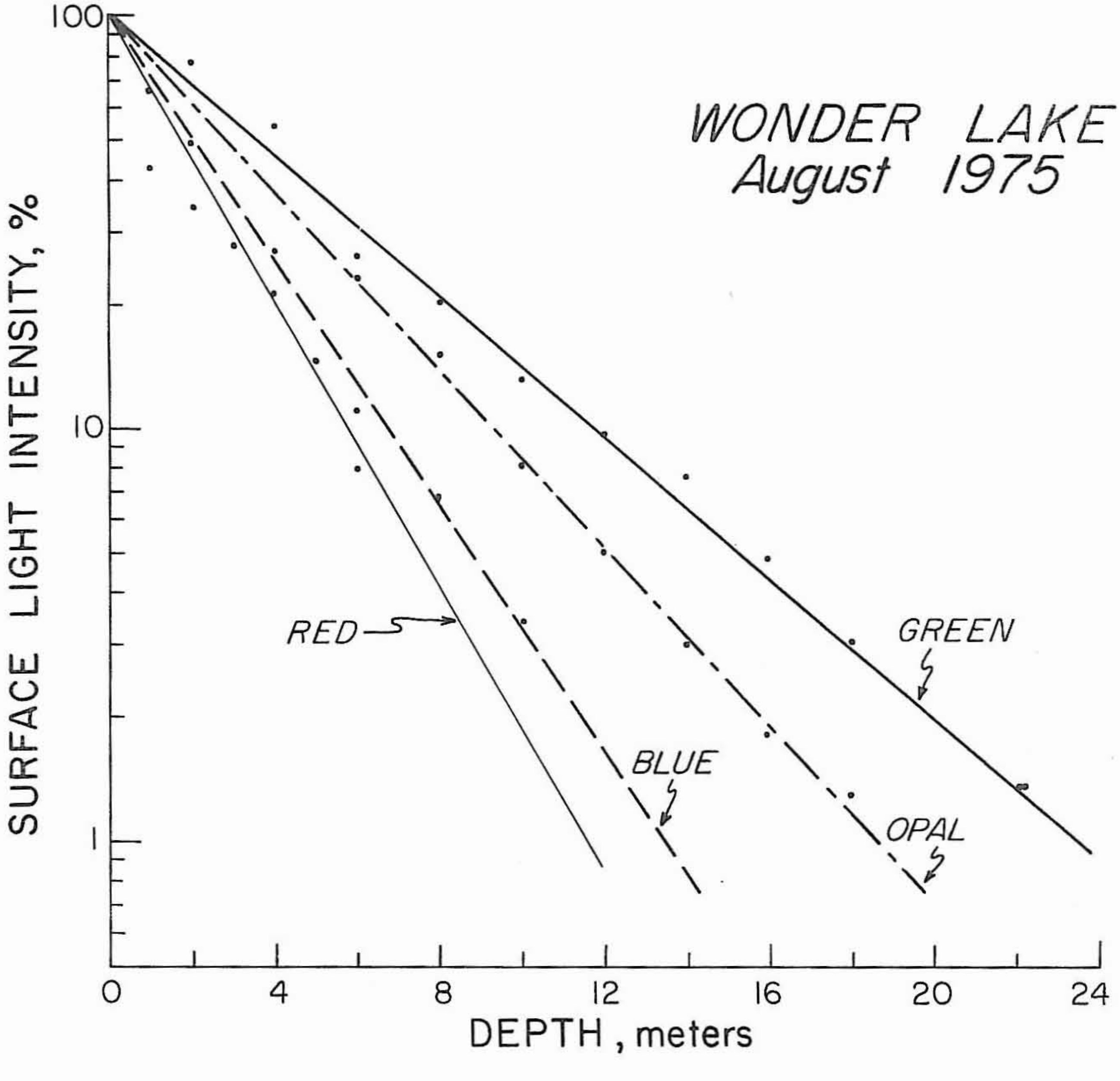

Figure 12: Light Penetration Diagram. Wonder Lake.

contain relatively more chlorophyll a concentrating at optimum light levels. Unfortunately, algal counts were not conducted so the species distribution through the water column is not known. Phaeopigments were not of measurable concentration in any of the samples.

Vascular Plants

Vascular hydrophyte colonization of Wonder Lake is very limited. The littoral area of the lake is small, with very little sediment accumulation. Only three areas were found to support submersed hydrophytes, with all three having gradual slopes with some, if only minor, sediment accretion. The first area is the shallow "shelf" zone near the Mt. McKinley National Park Wonder Lake campground, at the southernmost end of the lake. Here, very sparse growth of *Potamogeton richardsonii* was noted, and a few winter buds of a native milfoil (*Myriophyllum* sp.) were collected. No actively growing milfoil stalks were located, and it is probable that the population never flowers. The standing macrophyte crop of this area is estimated at less than 1 g/m^2 ash-free dry weight, over no more than 4 hectares. Clumps of *Chara* sp. were also noted in this area but were not sampled because this study was focusing on vascular hydrophytes and was not considering the macroalgae.

A second area of macrophyte colonization was discovered along the eastern shore of Wonder Lake in the vicinity of the Mt. McKinley Park Wonder Lake ranger station dock. In this area, *Potamogeton praelongus* was found in a colony covering less than ½ hectare. The standing crop biomass of this zone was estimated at 15-30 g/m^2 (ash-free). The plants in this zone were found to be covered with a dense growth of *Hydra* sp., similar to those noted in the youth camp area of Harding Lake. The third macrophyte colonization area was found at the northernmost end near the inlet and outlet, where a shallow, mucky shelf covers about 8 hectares. Here, dense, short-statured growths of vascular hydrophytes were found. The lack of flowering material made these individuals difficult to identify. There was probably at least one thin-leaved *Potamogeton* species present and possibly *Heteranthera dubia*, although Hulten's *Flora of Alaska* (1968) does not mention its presence in the state.

The vascular hydrophytes of Wonder Lake were found to be covered with large amounts of $CaCO_3$ (marl). This marl is deposited as the plants remove CO_2 from bicarbonate ions, allowing precipitation of the marl on plant leaves and stems. Marl deposition is most commonly found in hard-water lakes, where CO_2 gas is available in quantities too small to maintain plant growth rates, forcing utilization of the bicarbonate ions.

Nutrient Chemistry

The results of selected plant nutrient analyses on samples taken July 6-7, 1975, at Wonder Lake and August 16, 1975, at Paxson Lake are shown in Figures 13 and 14, respectively. The resulting profiles at Paxson Lake show the expected trends with depletion in the photogenic zone and accumulation in the phototrophic zone. It should be noted that Paxson Lake has a sizable inlet and outlet and the hydrology of the basin no doubt influences the shapes of these profiles in ways that cannot be understood without fairly intense hydrological measurements.

It should also be noted that, during the one short sampling period conducted by this group at Paxson Lake, migrating Red Salmon (*Oncorhynchus nerka*) were noted above Paxson Lake in the Gulkana River. These fish are known to spawn both above and below Paxson Lake (Van Wyhe and Peck, 1968) and they die after spawning. Thus, an important source of annual nutrient loading of the lake was present in the watershed, but it is likely that peak loading would be expected somewhat after the spawning activity (Brickell and Goering, 1970).

The relatively higher levels of nutrients (N and P) in the shallow water at Wonder Lake may be explained by several possibilities. These levels could be due to local concentration of plankters, since particulate fractions were not separated from dissolved fractions in the analyses. They could also be due to ongoing decomposition of the tissue of rooted aquatic plants as the period of active growth had not yet been reached, being late in the summer in this climatological area.* The phosphorous increase with depth could also be explained by the coprecipitation with $CaCO_3$, as marl was noted on the vascular hydrophytes the previous summer.

---

*F. C. Payne, 1974: personal communication.

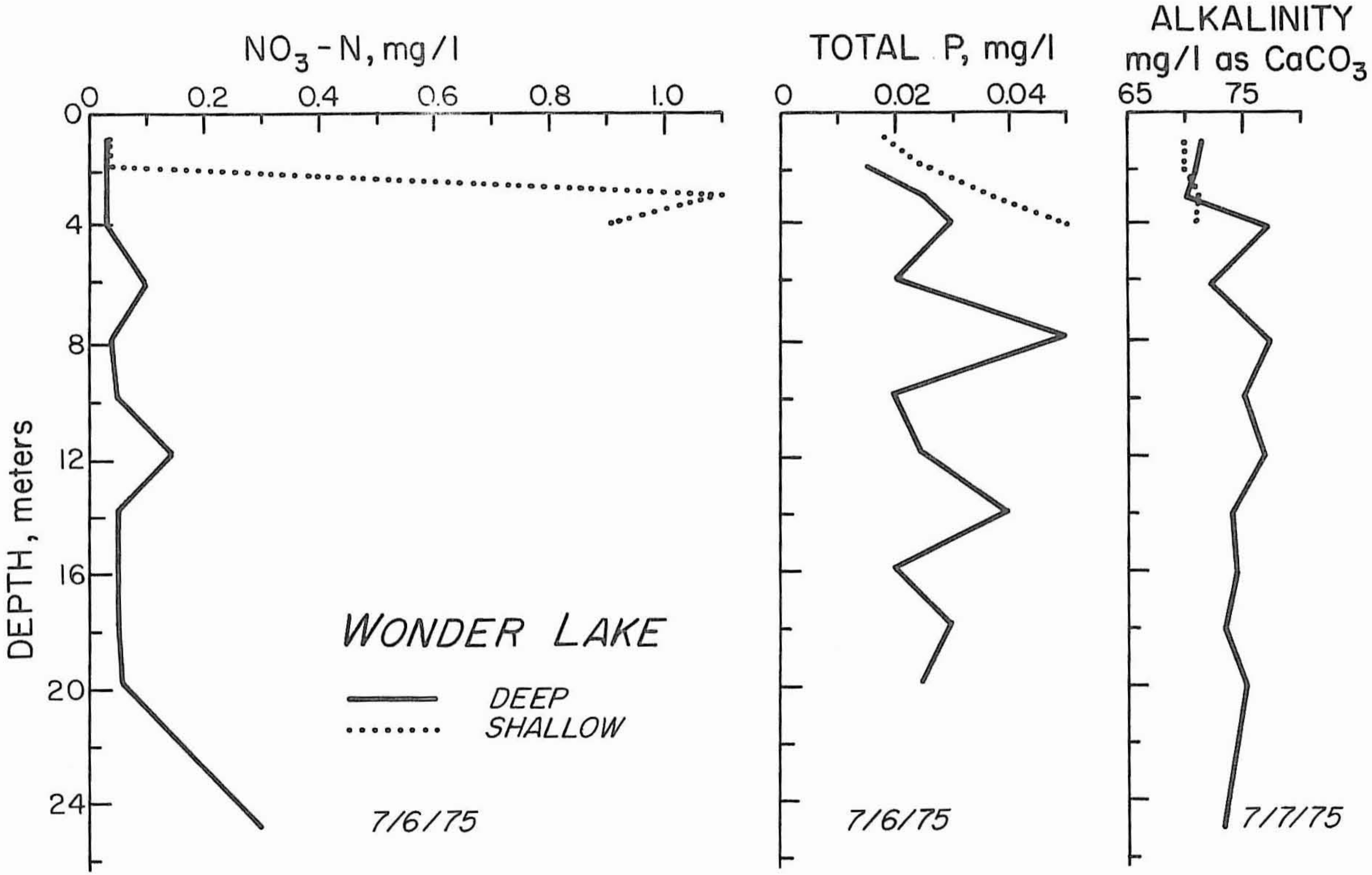

Figure 13: Selected Plant Nutrient Concentration Profiles. Wonder Lake.

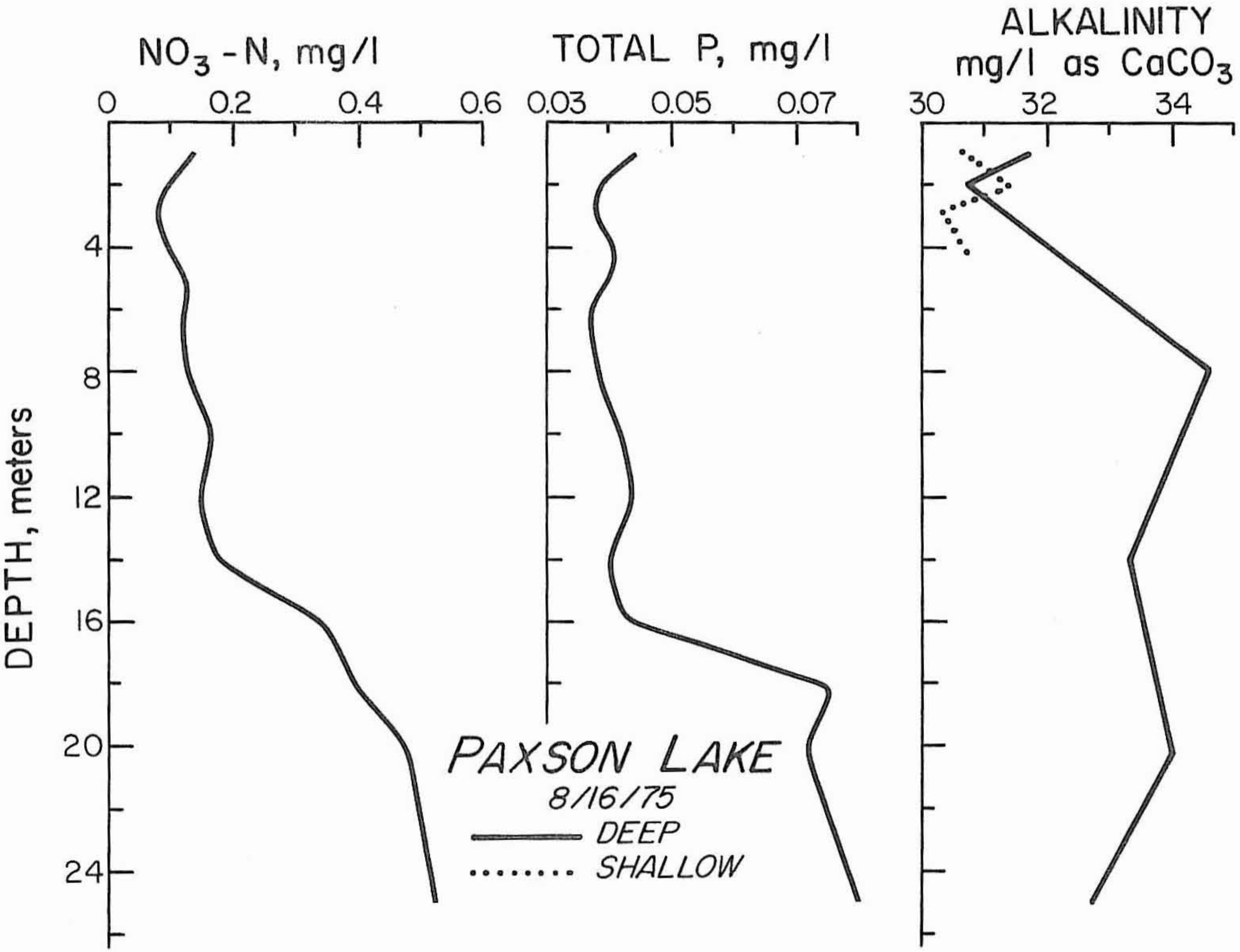

Figure 14: Selected Plant Nutrient Concentration Profiles. Paxson Lake.

The nutrient measurements of the deeper station at Wonder Lake have rather erratic profiles (Figure 13). This is probably the result of the effect of biological activity since conservative chemical substances, as represented by pH and conductivity, were nearly the same concentration throughout the water column measured (i.e. to 40 m) with pH at 7.8 and conductivity about 115 μmho/cm at 20°C with little variation.

Zooplankton

Zooplankton samples have not been analyzed for Wonder Lake. However, at Paxson Lake, four 20 m vertical hauls gave a dry weight of 0.0249 ± .0007 g. Three days earlier, five 20 m hauls at Harding Lake gave a dry weight of 0.0085 ± 0.0005 g. The use of a fine-meshed net for these hauls aids in capturing the larval (nauplius) forms of the zooplankton, but also captures some of the larger phytoplankton.

The following table contains the identification of the plankters caught in one of the replicate hauls.

TABLE I

PHYTOPLANKTON AND ZOOPLANKTON - PAXSON LAKE
(20 m vertical haul of 76 micron net)

Phytoplankton	Zooplankton
Ceratium sp.	*Ceratium* sp.
Oscillatoria sp.	*Heterocope septentrionalis*
Coscenodiscus sp.	*Kellicottia longispina*
Asterionella sp.	*Bosmina coregoni*
	Daphnia longiremus
	Cyclops sp.
	Diaptomus sp.
	Copepod nauplii
	unidentified stalked colonial rotifer

DISCUSSION

During the first year of this study and, indeed, until the completion of the field work, the morphometry of Wonder Lake was unknown and one of the most important tasks we set for ourselves was to map the bottom of this lake. The setting of the lake with hills plunging to the shore has, of course, hinted that the lake was deep. Thus it was no surprise to discover that the mean depth of this lake is approximately 39.8 m and that the hypolimnetic volume represents 82% of the total volume.

The very regular, flat-bottomed shape of the basin, however, was not surprising as the lake has long been known to be the result of glacial scouring of a valley with a terminal moraine dam. Generation of the morphometric map from the transect data showing extreme depths stimulated the thought that perhaps tectonic activity was a contributing formation activity. This idea has been supported by some evidence found by a State Geological Survey assistant that a fault runs down the center of the lake. This may partially explain why it is deeper than Paxson Lake which was formed by the same glaciation. The choice of this particular lake for comparison to Harding Lake seems excitingly coincidental when it is considered that the same type of evidence may explain why Harding Lake is considerably deeper than others of its formation group (Blackwell, 1965), which were formed chiefly by aggradation of the Tanana River. The limnological consequences of increased depth have been thoroughly covered by Rawson (1955) and others. Hayes and Anthony (1964), in analyzing data from 150 lakes in North America to develop an index of potential fish production, were able to assign 24% of variability to depth and 20% to area (both inverse relationships) while 18% was assignable to methyl orange alkalinity (direct relationship). Depth could thus be the equalizing factor in the comparison of the algal primary production of Paxson and Wonder Lakes when it is considered that Wonder Lake is about 3.3 times as deep as Paxson Lake, while Paxson Lake has about 6 times the surface area of Wonder Lake. The potential advantage of Paxson Lake's greater epilimnetic volume due to its windy setting is offset by its lesser clarity and light penetration.

Geomorphometrically, Wonder and Paxson Lakes are in the same setting of morphometric rock which can be contrasted to that of Harding Lake which lies in granitic surroundings,* which, of course, contribute fewer of the minerals important to plant growth. While both lakes lie in geomorphic settings that contribute comparable amount of plant nutrients, Paxson Lake's lower alkalinity, reflecting available carbon content, can perhaps be accounted for by the relatively higher flow-through of water in the basin compared to the almost closed or seepage basin of Wonder Lake.

The climatology of the area in consideration, that of interior subarctic Alaska, undoubtedly has a controlling influence on the productivity of lake ecosystems. While the establishment of an ice seal causes the winter thermal regime of a lake in this area to be close to that of a more temperate region, the ice seal is present for a greater length of time (early November to early June for Harding Lake). Solar insolation for this northern latitude is highly variable seasonally. Daylight varies from about 4-5 hours in December to over 21 hours at the summer solstice in June (Johnson and Hartman, 1969). Thus, lakes in this area experience high spring radiation flux while still ice-covered. The result of this phenomenon is that thermal stratification may be set up under the ice, particularly as the warmer water near the surface may be the low-salt meltwater from the ice and may be isolated from mixing with the lake by the salt-related density difference. This has been noted in many lakes in the area, especially shallow dystrophic lakes (Alexander and Barsdate, 1971). The possibility of less than complete reoxygenation in the spring is a real possibility for lakes of this climatic zone. This presents, indeed, an important basis for future study of lakes in interior Alaska.

The particularly short period during which aquatic primary productivity, especially that of the vascular hydrophytes, is possible is perhaps a controlling factor on such problems as blooms of phytoplankton and nuisance growths of vascular aquatic plants. The hypothesis examined in this study was disproved, at least for Wonder Lake where the primary production of the algae was seen

---

*D. B. Hawkins, 1975: personal communication.

to be higher than that of the vascular aquatic plants. This can be accepted as reasonable when it is understood that the arctic lakes considered by Hobbie (1973) are shallow enough to allow rooted vegetation over a relatively larger percentage of their surface area even though they are located further north in a climatic zone harsher to plant production.

The influence of the climatic zone is again seen when it is considered that both Harding and Wonder Lakes are seepage basins at best, with relatively long water residence times. While this is due to relatively small watershed-to-lake area ratios in both cases, the low precipitation of this climatic zone, with an annual mean of about 35 cm (Johnson and Hartman, 1969), is very influential. This study, therefore, while answering many questions, still has generated extensive food for thought concerning similarity and differences of lakes of the central Alaska Range.

BIBLIOGRAPHY

Alexander, V., and R. J. Barsdate (1971). Physical limnology, chemistry and plant productivity of a taiga lake. *Int. Revue ges. Hydrobiol. 56:* 825-872.

Blackwell, M. J. (1965). Surficial geology and geomorphology of the Harding Lake area, Big Delta quadrangle, Alaska. Unpublished M.S. thesis. Fairbanks, Alaska, Library, University of Alaska. 91 pp.

Brickell, D. C., and J. J. Goering (1970). Chemical effects of salmon decomposition on aquatic ecosystems. IN: Murphy, R. S. and D. Nyquist (eds.). *Water Pollution Control in Cold Climates*. Proceeding of an International Symposium, University of Alaska, July 22-24, 1970. U.S. Government Printing Office, Washington, D.C. Stock Number 5501-028. 332 pp.

Dugdale, R., and J. T. Wallace (1960). (Note) Light and dark bottle experiments in Alaska. *Limnol. Oceanog. 5:*230-231.

Golterman, H. L., ed. (1969). *Methods for Chemical Analysis of Fresh Waters*. IBP Handbook No. 8. Blackwell Scientific Publications. Oxford and Edinburg. 166 pp.

Hayes, F. R., and E. H. Anthony (1964). Productive capacity of North American lakes as related to the quantity and the trophic level of fish, the lake dimensions, and the water chemistry. *Trans. Am. Fish. Soc. 93:*53-57.

Hobbie, J. E. (1973). Arctic Limnology, a review. IN: Britton, M. E. (ed.) *Alaska Arctic Tundra.* Arctic Institute of North American, Technical Paper No. 25. Washington, D.C.:127-168.

Hulten, E. (1968). *Flora of Alaska and Neighboring Territories: A Manual of the Vascular Plants*. Stanford University Press, Stanford, Ca. 1008 pp.

Hutchison, G. E. (1957). *A Treatise on Limnology, Volume 1.* John Wiley and Sons, Inc., New York. 1015 pp.

Johnson, P. R., and C. W. Hartman (1969). *Environmental Atlas of Alaska.* Institute of Arctic Environmental Engineering, Institute of Water Resources, University of Alaska, Fairbanks. 109 pp.

Rawson, D.S. (1955). Morphometry as a dominant factor in the productivity of large lakes. *Verh. Inst. Ver. Limnol. 12:*164-175.

Stainton, M. B. (1974). Simple efficient reduction column for use in the automated determination of nitrate in water. *Analytical Chemistry, 46:* 1616.

Strickland, J. D. H., and T. R. Parsons (1965). A manual of sea water analysis. Bulletin No. 125: Fisheries Research Board of Canada, Ottawa. 203 pp.

U.S.E.P.A. (1974). Methods for chemical analysis of water and wastes. Methods Development and Quality Assurance Research Laboratory NERC Cincinnati, Ohio. 298 pp.

Van Wyhe, G. L., and J. W. Peck (1968). A limnological survey of Paxson and Summit Lakes in Interior Alaska. Alaska Department of Fish and Game. Information Leaflet 124:40 pp.

Vollenweider, R. A., ed. (1969). A Manual on Methods for Measuring Primary Production in Aquatic Environments, IBP Handbook No. 12. F. A. Davis Company, Philadelphia, Pa. 213 pp.

Wetzel, R. G. (1964). A comparative study of the primary productivity of higher aquatic plants, periphyton and phytoplankton in a large shallow lake. *Int. Rev. ges. Hydrobiol. 49:*1-61.