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Lake Tanganyika Geochemical and Hydrographic Study: 1973 Expedition

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LAKE TANGANYIKA GEOCHEMICAL

AND

HYDROGRAPHIC STUDY:

1973 EXPEDITION

Compiled by:

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I. INTRODUCTION

This report describes the work carried out on Lake Tanganyika during a cooperative expedition in February, 1973. The proposal for such an expedition was initiated by correspondence between H. Craig of the Scripps Institution of Oceanography, University of California, G. W. Coulter of the Burundi Fishery Research Project, and C. H. Clay, FAO, Rome. Permission to carry out research in Lake Tanganyika with the Burundi Fishery Project (FAO) was kindly granted by the Directeur des Eaux et Forets, Burundi, and permission to work with project staff and facilities was given by the Coordinator of Lake Projects, FAO, Rome.

This study of Lake Tanganyika originated in the desire to apply the geochemical methods and techniques recently developed for oceanographic research to the problems encountered in trying to understand the circulation and chemistry of a large and deep lake. In this respect, Lake Tanganyika is of outstanding scientific interest to the international community of oceanographers, limnologists, and hydrologists. In many ways Lake Tanganyika resembles the oceans, especially in the long "residence time" of deep water relative to replacement by mixing with surface water. This time is estimated to be of the order of 2000 years in both Lake Tanganyika and in the oceans. In the ocean, the mixing is rapid enough, and the rate of consumption of oxygen in the deep water is slow enough, so that most deep ocean water maintains a significant concentration of dissolved oxygen and supports life. However, in certain areas such as the tropical waters of the Eastern Pacific and in some of the deep trenches, the oxygen is entirely consumed and the waters resemble the deep water of Lake Tanganyika which is anoxic and does not support life. In both cases the decomposition of sinking organic matter takes place under anaerobic conditions and

a very special chemistry develops which characterizes the production of nutri-
ent elements in soluble form in the deep water. Since it is the upwelling of
these nutrient elements which supports the productivity of the surface waters,
it is vitally important to understand the chemical processes in the deep water
which produce the nutrients, and the physical processes which bring the nutri-
ent elements to the surface to support the fish and plankton population. The
study of these chemical and physical processes which support the productivity
in surface waters is a meeting-ground in which oceanographers and limnologists
share a common interest in a research area of vital importance for the exploit-
ation of world's aqueous environment.

Naturally occurring radioactive isotopes such as radiocarbon (carbon-14)
radium, and silicon-32, provide clocks with time-scales ranging from 500 to
5,000 years, which are currently being used in oceanographic studies to measure
circulation and mixing rates in the sea which are so slow that they cannot be
studied by any other technique. At the same time, man-made radioisotopes pro-
duced by nuclear explosions in the atmosphere, such as tritium (hydrogen-3),
enter the water surface and mix downward on a time scale of the order of 20
years. Such isotopes provide information on the rate of downward circulation
of material into the depths. Finally, the measurement of certain natural
trace-element isotopes such as lead-210, which is chemically scavenged by organ-
isms, provides a time scale for the rate at which particulate matter sinks from
the surface to supply the nutrients to the deep water.

All of these, and many other recent techniques for oceanic research, can
be fruitfully applied to developing our understanding of the physical and chem-
ical regime of a deep lake such as Tanganyika. Thus our objective in this pre-
liminary research project on Lake Tanganyika was to obtain measurements of the

distribution of the most important of these geochemical parameters, in order to provide a basic framework for further detailed studies based on these methods. Such studies of the physical and chemical processes by which nutrients reach the surface waters are basic to the project research on biological and fish production now being carried out by the Burundi FAO project.

The 1973 Expedition

Our work on the lake itself was done aboard the FAO boats "Lady Alice II" and "Banga-Banga" based in Bujumbura. The personnel included Professor and Mrs. H. Craig and F. Dixon from Scripps Institution of Oceanography, Professor J. Edmond of the Massachusetts Institute of Technology, Dr. G. Coulter and Mr. W. Ferro of the Burundi Fishery Project, and boat crew members A. Bolingo, J. Bacinoni, and E. Nikomeze.

Five hydrographic stations were occupied in the northern part of the lake, and 23 hydrographic casts were made during the six days at sea, during which more than 400 samples of lake water were collected.

The following stations were occupied:

Station 1: seven miles off Kigoma in 1350 meters of water.

Station 2: off Nyanza Lac (480 meters).

Station 3: off Kagongo (375 meters).

Station 4: off Magara (308 meters).

Station 5: 10 miles west of Bujumbura (210 meters).

Numerous water samples were also collected from the Ruzizi River, the Muzazi River and one of its tributaries, and from streams at Magara, Mutumba, and Kagongo. These river samples are most important for studying the chemical "budgets" of the major and minor elements in the lake, as they provide a measure of the input of all chemical species by runoff from the surrounding level.

In addition to the facilities, boats, and equipment provided by FAO, Burundi, specialized equipment was brought to Burundi from the Scripps Institution of Oceanography and MIT for interim use on our mission. Transit entry of this equipment duty-free, was very kindly authorized by the Director of Customs, according to the request by the Directeur des Eaux et Forets.

Sample Collection and Analysis

Over 400 samples ranging in amounts from 50 ml. to 20 liters, were collected at the five stations. The total amount of water shipped to the U.S. for analysis was 400 kg. Most of the analytical work has been carried out in the laboratories of H. Craig at Scripps Institution of Oceanography and J. Edmond at MIT, but specialized analytical work has also been done at the University of Miami (tritium analyses) and at the Tata Institute of Fundamental Research, Bombay, India (silicon-32, uranium, thorium). At Scripps and MIT water has been analysed for major and minor cations and anions, nutrient substances, stable and radioactive isotopes of water (deuterium and oxygen-18), dissolved gases, carbon isotope ratios, trace elements, radium, radioactive lead-210, etc.

The physical separation of the participants in the field and analytical work, and the heavy involvement of several of us in a nine-month Pacific Ocean expedition program during 1973-1974, have precluded the preparation of an integrated and logically-arranged presentation of the data in this report. In order to speed the preparation of this report, we have thus chosen to present the results to-date as tabulated at each of the participating institutions who measured the data. The following sections thus present the measurements made at Scripps, MIT, University of Miami (tritium data), and UNDP, Burundi (bathythermograph measurements).

Samples were also collected for profiles of Ra-228 and Si-32 by immersing chemically treated fibers on a moored line at Station 1 for 27 hours; these samples are being analyzed at the Physical Research Laboratory at Ahmedabad, India, by B. L. K. Somayajulu and D. Lal, and these results will be reported at a later date.

It is a pleasure to thank the Government of Burundi and its representatives in Bujumbura for permission to carry out this study of Lake Tanganyika, and to express our gratitude to the FAO for permission to use the Burundi facilities. We are also grateful to Dr. John Moes, former Director of the Lake Tanganyika Fishery Research Project at Kigoma, Tanzania, for assistance in working out of Kigoma, and to Dr. John Twiss of the U. S. NSF-IDOE Program for assistance in setting up the program. Finally, we wish to thank Dr. Gote Ostlund for participating in the analytical program and measuring the tritium samples, in the midst of a heavy program of oceanographic research.

Ms. Kris Beard at SIO carried out the preparation of this report with maximum dispatch. Work at the Scripps Institution of Oceanography was supported by the National Science Foundation on Grant # NSF GA-27283.

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SECTION II

STATION POSITIONS

SAMPLING LOCATIONS (Lake surface water, rivers)

STATION 1:   Cast list, bottle depths, thermometric data, depths sampled

BT DATA: Stations 1-5 and section from Station 1-2

Sampling and Locations

The hydrographic sampling aboard Lady Alice II was done with non-metallic PVC "Niskin" bottles (General Oceanics, Miami, Florida). Both 5-liter (numbers 50 - 55) and 30-liter (numbers 1 - 4) bottles were used. Thermometric measurements were made with the reversing protected and unprotected thermometers from SIO and WHOI. The thermometric data were reduced by Arnold Mantyla at the Geosecs Operations Group, SIO, and we record our gratitude to him for this service.

Station 1 was the deepest station occupied (1350 meters). Our winch allowed us to sample to a depth of only 867 meters, with the 30-liter bottles. Subsequent work was done entirely with 5-liter bottles; multiple cast sampling was used for the large samples (20 liters) taken for radium and other trace elements. Some 19 casts were required at Station 1; a detailed listing is included in this section. At Stations 2 - 5 only single casts were taken and these are tabulated with the hydrographic data in Section III. No thermometers were available after Station 1 as it was necessary to fly them to Dakar to meet the R/V KNORR for continuation of the Atlantic Geosecs expedition work.

River samples are numbered from north to south for convenience. Samples 7 to 9 in Tanzania and Zambia, and lake surface samples A, B, and C, south of Station 1, were collected by G. Coulter one month after the station work was completed. Rivers were sampled just above their mouths, generally at the intersection with a road along the lake.

The station and sampling locations are shown in Figure 1.

Additional samples for chloride, nutrient, and isotopic analysis have been collected biweekly at Station 5 ("Bujumbura") and at the Ruzizi River mouth, by Mr. Wouter Ferro, since August, 1973.
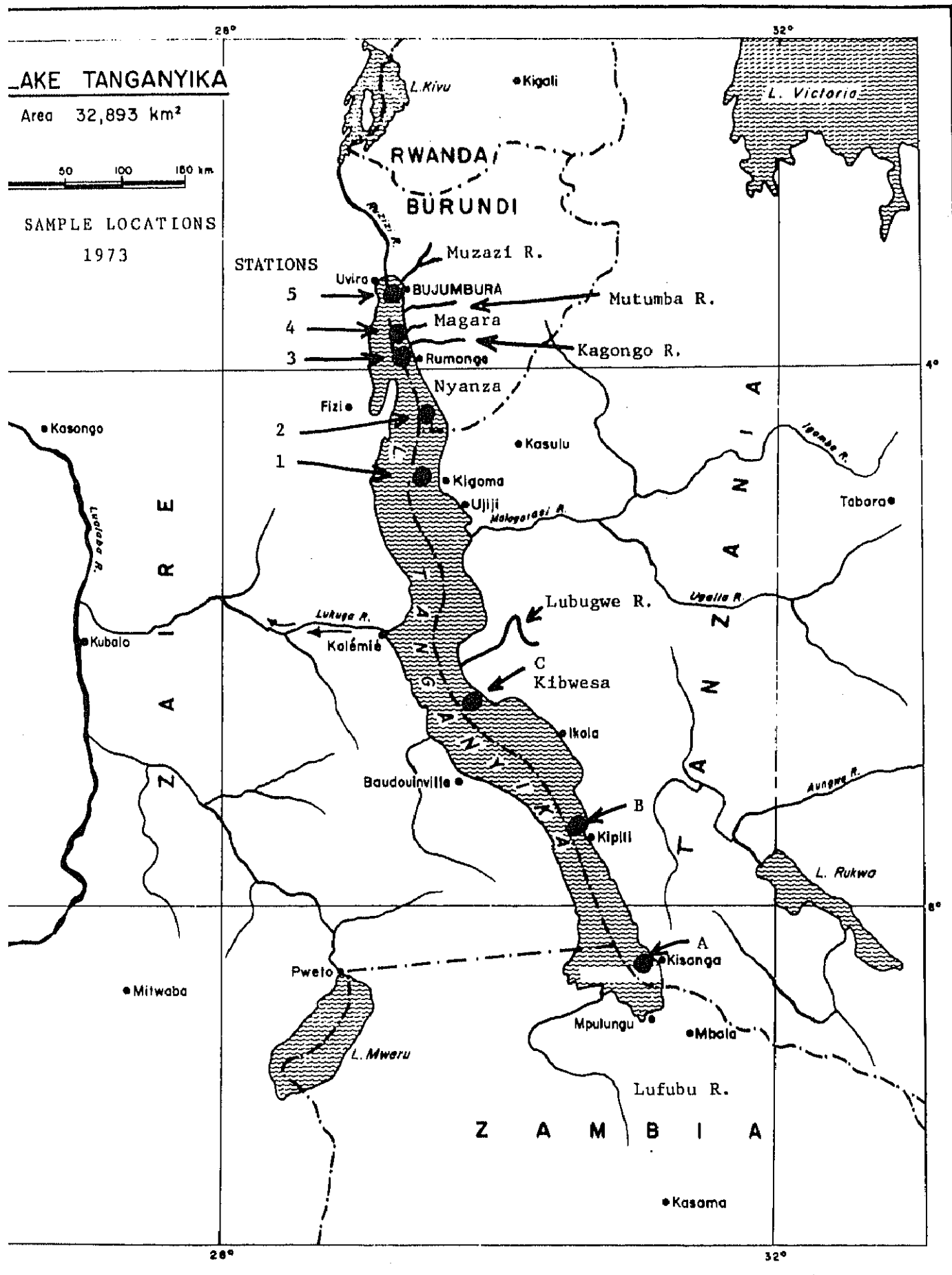
Figure 1. Location of Stations, Lake surface samples, and River samples

LAKE TANGANYIKA 1973:   STATION POSITIONS

STATION 1.   "Kigoma Station", 12.5 km (7 naut. miles) west of Kigoma,
Tanzania; $4^O51'$ S, $29^O29.5'$ E.   Depth = 1350m.

STATION 2.   "Nyanza Station", 15 km (8.1 naut. miles) west of Nyanza Lac;
approx. $4^O21'$ S, $29^O27'$ E.   Depth = 480m.

STATION 3.   "Kagongo Station", bearings: 120°; 16 km (8.6 naut. miles) to
Rumonge; 40°, 8.5 km (4.6 naut. miles) to Kagongo Chateau.
approx. $3^O54.5'$ S, $29^O19'$ E.   Depth = 380m.

STATION 4.   "Magara Station", bearings: 120°, 5.5 km (3 naut. miles) to Magara,
approx. $3^O42'$ S, $29^O18'$ E.   Depth = 308m.

STATION 5.   "Bujumbura Station", bearings: 51°, 17.6 km (9.5 naut. miles)
to Bujumbura, approx. $3^O29'$ S, $29^O14'$ E.   Depth = 210m.

LAKE SURFACE WATER SAMPLES

A.   "Kasanga":   5.5 km (3 naut. miles) off Kasanga, Tanzania, approx. 8°28' S,
31°07' E.   Collected 28 March, 1973.

B.   "Kipili":   Approximately 11 km (6 naut. miles) off Kipili coast, Tanzania,
approx. 7°17' S, 30°27' E.   Collected 31 March, 1973.

C.   "Kibwesa":   3.7 km (2 naut. miles) west of Kibwesa, Tanzania, approx.
6°30' S, 29° 55' W.   Collected 2 April, 1973.

LAKE TANGANYIKA '73

RIVER SAMPLE LOCATIONS

LOCATION NUMBER	LOCATION	DATE SAMPLED
1	Ruzizi River, Burundi	15 February 1973
2	Muzazi River, Burundi	15 February 1973
3	Muzazi Tributary, Burundi	15 February 1973
4	Mutumba River, Burundi	16 February 1973
5	Ruzibazi River (Magara), Burundi	16 February 1973
6	Kagongo River, Burundi	16 February 1973
7	Malagarazi River, Tanzania	3 April 1973
8	Lubugwe River (Kungwe Mountain area, north of Kibwesa), Tanzania	2 April 1973
9	Lufubu River, Zambia	24 March 1973

STATION 1: Complete cast list

CAST NO.	DATE 1973	Local Time (Z-2) START	END	TERMINAL READING(m)	REMARKS
BT	18 Feb	1430	1440	275	
1	18 Feb	1500	1800/19	1350	Moored Fiber cast, 27 hours, for Ra^{228}, Si^{32}
2*	"	1625	1710	100	Shallow cast
3*	"	1930	0230	973	Deep cast with 30-liter bottles
4	19 Feb	1045	1125	100	Thermometer at 5m
5	"	1132	1152	100	
6	"	1220	1247	100	
7	"	1303	1327	100	
8	"	1332	1338	5	Surface cast, 1 bottle
9	"	1340	1344	5	Surface cast, 1 bottle
10	"	1347	1349	5	Surface cast, 1 bottle
11*	"	1405	1510	450	Intermediate cast
12*	"	1605	1653	450	Intermediate cast
13	"	1755	1830	450	
14	"	1900	1940	450	
15*	20 Feb	1455	1531	225	Intermediate cast
16	"	1640	1709	207	
17	"	1725	1746	155	
18	"	1803	1844	200	
19	"	1900			Surface bucket samples

*Reversing thermometers on bottles on these casts.

STATION 1: Bottle depths by cast
Wire angle=0°, all casts
<u>Depths:</u> thermometric when temperatures
indicated, otherwise wire depths
All times are Local Time (Z-2)

STATION – CAST	BOTTLE NUMBER	DEPTH (meters)	TEMP (deg C)	MESSENGER TIME (LOCAL)
1-2	51	5	27.34	1646/18 Feb.
	52	27	27.14	
	53	45	26.15	
	54	63	24.82	
	55	91	24.14	
1-3	51	625	23.29	2008/18 Feb.
	1	635		
	52	721	23.30	
	2	731		
	53	818	23.26	
	3	828		
	54	867	23.25	
	4	877		
1-4	53	5	27.35	1119/19 Feb.
	54	50		
	55	100		
1-5	53	5		1145/19 Feb.
	52	50		
	51	100		

STATION 1: Bottle depths by cast, (continued)

STATION -CAST	BOTTLE NUMBER	DEPTH (meters)	TEMP (deg C)	MESSENGER TIME (LOCAL)
1-6	51	5		1240/19 Feb.
	52	45		
	53	50		
	54	95		
	55	100		
1-7	51	5		1317/19 Feb.
	52	45		
	53	50		
	54	95		
	55	100		
1-8	52	5		1333/19 Feb.
1-9	55	5		1344/19 Feb.
1-10	52	5		1348/19 Feb.
1-11	51	250	23.44	1443/19 Feb.
	52	300	23.38	
	53	350	23.37	
	54	400	23.31	
	55	450	23.33	

STATION 1: Bottle depths by cast, (continued)

STATION –CAST	BOTTLE NUMBER	DEPTH (meters)	TEMP (deg C)	MESSENGER TIME (LOCAL)
1–12	51	250	23.46	1634/19 Feb.
	52	300	23.38	
	53	350	23.36	
	54	400	23.34	
	55	450	23.32	
1–13	51	250		1810/19 Feb.
	52	300		
	53	350		
	54	400		
	55	450		
1–14	52	300		1925/19 Feb.
	55	450		
1–15	51	120	23.82	1519/20 Feb.
	52	144	23.66	
	53	168	23.55	
	54	187	23.47	
	55	216	23.47	
1–16	51	150		1700/20 Feb.
	52	192		
	53	197		
	54	202		
	55	207		

STATION 1: Bottle depths by cast, (continued)

STATION 1:   Bottle depths by cast, (continued)

STATION CAST	BOTTLE NUMBER	DEPTH (meters)	TEMP (deg C)	MESSENGER TIME (LOCAL)
1-17	52	5		1737/20 Feb.
	53	145		
	54	150		
	55	155		
1-18	51	70		1839/20 Feb.
	52	125		
	53	150		
	54	175		
	55	200		
1-19	—	Surface (bucket)		1900/20 Feb.

STATION 1: Depths sampled and corresponding bottle numbers

Depth (m)	Sample Number (cast number - bottle number)
0	19 - "Bucket"
5	2-51, 4-53, 5-53, 6-51, 7-51, 8-52, 9-55, 10-52, 17-52
27	2-52
45	2-53, 6-52, 7-52
50	4-54, 5-52, 6-53, 7-53
63	2-54
70	18-51
91	2-55
95	6-54, 7-54
100	4-55, 5-51, 6-55, 7-55
120	15-51
125	18-52
144	15-52
145	17-53
150	16-51, 17-54, 18-53
155	17-55
168	15-53
175	18-54
187	15-54
192	16-52

STATION 1: Depths sampled and corresponding bottle numbers, (continued)

Depth (m)	Sample Number (cast number - bottle number)
197	16-53
200	18-55
202	16-54
207	16-55
216	15-55
250	11-51, 12-51, 13-51
300	11-52, 12-52, 13-52, 14-52
350	11-53, 12-53, 13-53
400	11-54, 12.54, 13-54
450	11-55, 12-55, 13-55, 14-55
625	3-51
635	3-1*
721	3-52
731	3-2*
818	3-53
828	3-3*
867	3-54
877	3-4*

*30-liter Niskin bottle. All others are 5-liter Niskin bottles.

BATHYTHERMOGRAPH MEASUREMENTS

BT casts were taken on each station. Between Station 1 and Station 2, casts were made approximately each 5.5 nautical miles from Station 1. The slides were read under a low power microscope with an ocular micrometer. The accuracy of the temperature measurements is generally about 0.1°C. Mr. Wouter Ferro made the BT measurements. Times listed are LOCAL TIME (Local time zone -2), distances in nautical miles.

STATION 1 "Kigoma Stn" 1430/Feb. 18		~5.5 miles N of Station 1 1950/Feb. 20		~11 miles N of Station 1 2045/Feb. 20	
TEMP (deg C)	DEPTH (m)	TEMP (deg C)	DEPTH (m)	TEMP (deg C)	DEPTH (m)
27.34	1	27.51	1	27.82	1
27.23	7	27.25	10	27.55	6
27.11	23	27.14	18	27.30	16
26.96	27	27.00	20	27.23	23
26.85	28	26.70	24	27.11	25
26.48	37	26.44	34	26.70	26
25.84	48	25.79	46	26.51	38
25.45	49	25.10	55	26.31	40
24.31	77	24.79	60	25.51	52
24.21	82	24.53	71	25.34	53
24.13	96	24.11	84	25.20	55
23.94	108	23.90	101	24.91	57
23.87	122	23.60	158	24.42	75
23.82	147	23.58	200	24.38	79
23.65	175	23.48	275	24.28	83
23.51	223			24.04	95
23.43	275			23.90	105
				23.72	142
				23.60	171
				23.52	275

Secchi disc
17 m

Bathythermograph Measurements, (continued)

~16.5 miles N of Station 1 2200/Feb. 20		~22 miles N of Station 1 2310/Feb. 20		~27.5 miles N of Station 1 0015/Feb. 21		STATION 2 "Nyanza Stn " 0125/Feb. 21	
TEMP (deg C)	DEPTH (m)	TEMP (deg C)	DEPTH (m)	TEMP deg C	DEPTH (m)	TEMP (deg C)	DEPTH (m)
27.79	1	27.87	1	28.00	1	27.73	1
27.20	27	27.42	10	27.70	3	27.70	3
26.82	30	27.34	20	27.51	7	27.39	12
26.51	33	27.20	26	27.42	11	27.21	15
26.34	40	26.79	29	27.25	15	27.06	25
26.17	44	26.56	33	27.10	28	26.23	32
25.90	46	26.39	36	26.62	30	25.97	35
25.00	55	26.00	41	25.73	38	25.70	37
24.56	63	25.87	45	25.45	43	25.54	44
24.14	88	25.45	48	25.25	45	24.68	56
23.89	117	24.96	54	24.99	51	24.18	87
23.62	163	24.65	59	24.84	59	23.76	132
23.56	200	24.53	63	24.79	61	23.58	185
23.51	275	24.39	67	24.65	63	23.49	275
		23.96	101	24.51	69		
		23.90	119	24.34	72		
		23.69	155	24.11	79		
		23.65	176	23.97	95		
		23.56	205	23.79	142		
		23.52	275	23.66	168		
				23.55	205		
				23.51	275		

Bathythermograph Measurements, (continued)

STATION 3 "Kagongo Stn" 0745/Feb. 21		STATION 4 "Magara Stn" 1410/Feb. 21		STATION 5 "Bujumbura Stn" 1640/Feb. 21	
TEMP (deg C)	DEPTH (m)	TEMP (deg C)	DEPTH (m)	TEMP (deg C)	DEPTH (m)
27.42	1	27.39	1	27.31	1
27.37	13	27.31	4	27.24	5
27.28	19	27.23	19	27.14	24
27.18	31	27.14	24	27.08	25
27.06	35	26.87	26	26.42	26
26.25	39	26.59	31	26.14	30
26.17	40	25.90	32	25.86	32
25.37	43	25.59	35	25.61	37
25.20	47	25.39	39	25.22	42
24.93	50	25.31	44	25.00	47
24.51	63	24.85	53	24.78	53
24.37	76	24.54	62	24.63	61
24.17	88	24.20	83	24.35	71
24.11	95	24.08	102	24.17	80
24.00	100	23.90	117	24.03	103
23.93	120	23.79	142	23.91	112
23.65	173	23.58	205	23.73	160
23.56	215	23.49	275	23.69	163
23.56	275			23.59	189
				23.51	208

SECTION III

HYDROGRAPHIC DATA, MEASUREMENTS AT SIO

1. Hydrographic data: T, Cl

2. ΣCO_2, C^{13}/C^{12} ratios

3. Radium-226

4. Lead-210

5. Helium and He^3/He^4 ratios

6. Stable isotopes of water: HDO, H_2O^{18}

7. References

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Oceanography

II-1. Hydrographic Data

Thermometric depths and temperatures are tabulated for Station 1 where thermometers were available; for Stations 2 - 5 the temperatures listed are crudely interpreted from the BT data. The chloride measurements were made by amperometric titration, normalized with standard solutions. The precision of the overall data is about ±0.2 ppm, although internally within a single series such as Cast 1, a precision of about ±0.1 ppm can be maintained.

The temperature and chloride profiles at Station 1 are shown in Figure 2. The chloride data show a well-mixed surface layer extending to at least 45m, and a completely uniform profile below 100 meters, with a concentration of 27.8 ppm. At this station the transition from aerobic water to anoxic water with H_2S replacing O_2 takes place at 100m. The temperature profile shows a well-developed summer thermocline at 50m, the base of the mixed-layer. For comparison, the winter (August) profile of Capart (1952) is superimposed on the profile. The seasonal difference is quite noticeable to 150m, and Capart (1952) states that this difference is actually observable to depths of 200 to 250m.

The deep water temperatures show a continual decrease to 867m, where we recorded the lowest value, 23.25°C. Capart (1952) does not give his 1947 temperature profile explicitly, but he records a mean value of 23.45° at 200m, and states that he observed a temperature in-situ minimum between 500 and 800 meters, with temperatures from 23.25 - 23.28° (see Figure 2). Our data are 0.02° greater at 200m (which may be seasonal), and 0.03° greater in the range 500-800m, with no indication of a minimum in that region. In general, one can say that the deep water has warmed less than 0.03° in 30 years, i.e. at a rate less than 0.001°/year.

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Our temperature profile shows an apparent discontinuity at about 250m
(Figure 1) where it is impossible to reconcile the profiles above and below in
single smooth curve. The profiles above and below this depth were measured
one day apart. Figure 3 shows the profile in this depth range on an expanded
scale, together with the bathythermograph record made just prior to Casts 11 and
2 on 19 February. It is evident that the BT profile is smoothly continuous with
the temperatures from Casts 11 and 12, while Cast 15, 24 hours later, shows a dis-
placed profile. This displacement may record the passing of an internal wave at
50 meters depth. The same displacement can be observed in the tritium and total
O_2 profiles at these depths; these components were sampled on the same casts.

The chloride data from 1973 compare very closely with the 1946-1947 Belgian
expedition data. Our station data, and surface water values at Locations A, B,
and C, indicate mean surface water concentrations of 26.5 ppm in the northern
basin and 27.1 ppm in the southern basin, and a concentration of 27.8 or 27.9 ppm
in the deep water. Kufferath (1952) also does not give the Belgian data explicitly
but he records a surface value of 27.0, and a value of 27.9 at 1300m, in the south-
ern basin (Station 161), in precise agreement with the present data. Degens et
al. (1971) record a constant value of 22±1 ppm throughout the water column, which
appears to be incorrect on the basis of the agreement of our data and the 1946-47
Belgian data.

The river data indicate that the Ruzizi and Malagarazi (Cl = 14 ppm) are the
principal suppliers of chloride to the lake. It is evident that the deep water
of the lake has been derived from colder, more saline water than any now available,
although the chloride difference between surface and deep water probably depends
principally on the status of the Lukuga River, the only lake discharge, as the
mixed-layer deficit would be made up in about 10 years if the Lukuga were closed
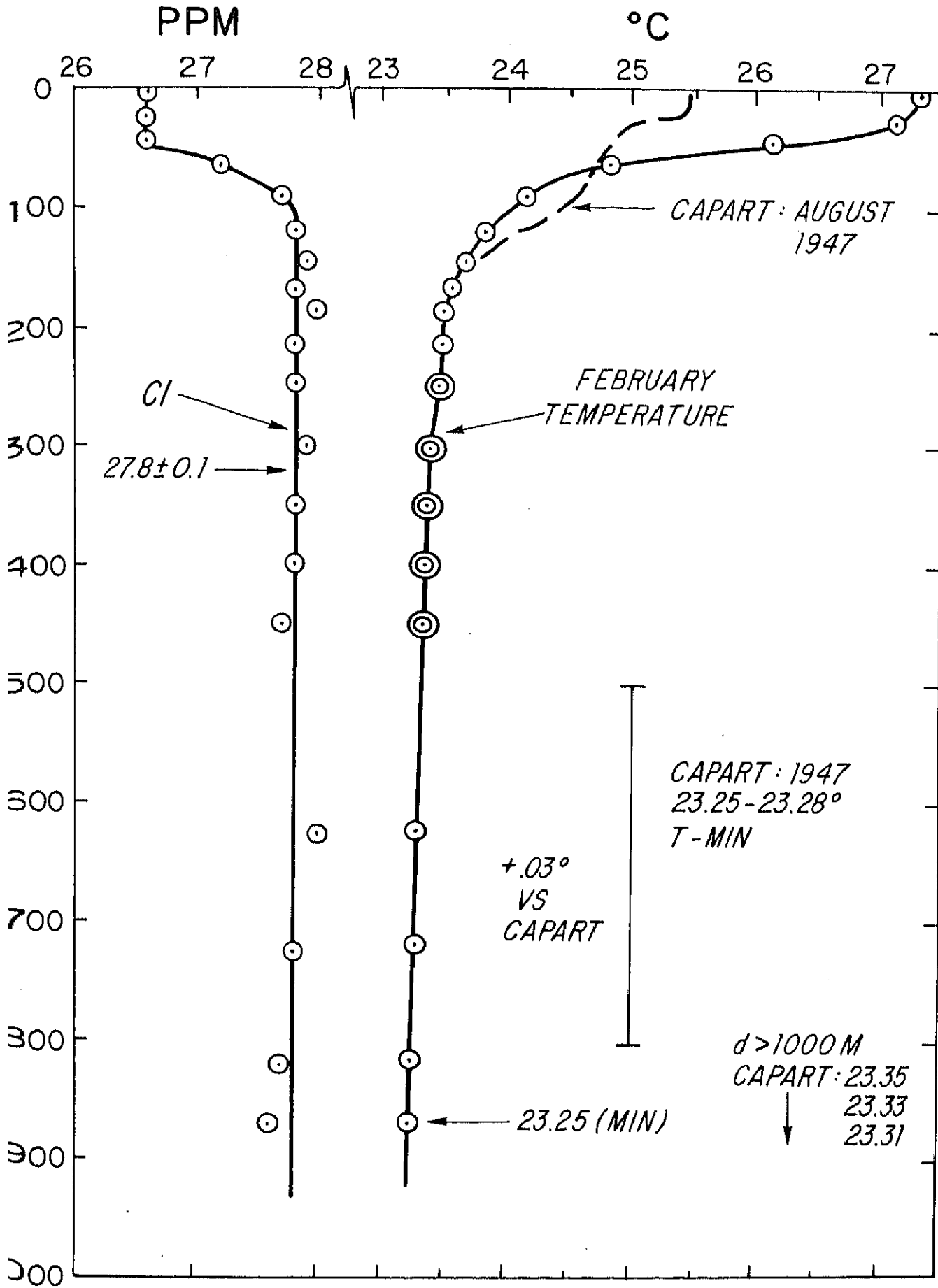again.

Figure 2.   Temperature and chloride profiles at Station 1 ("Kigoma Station")
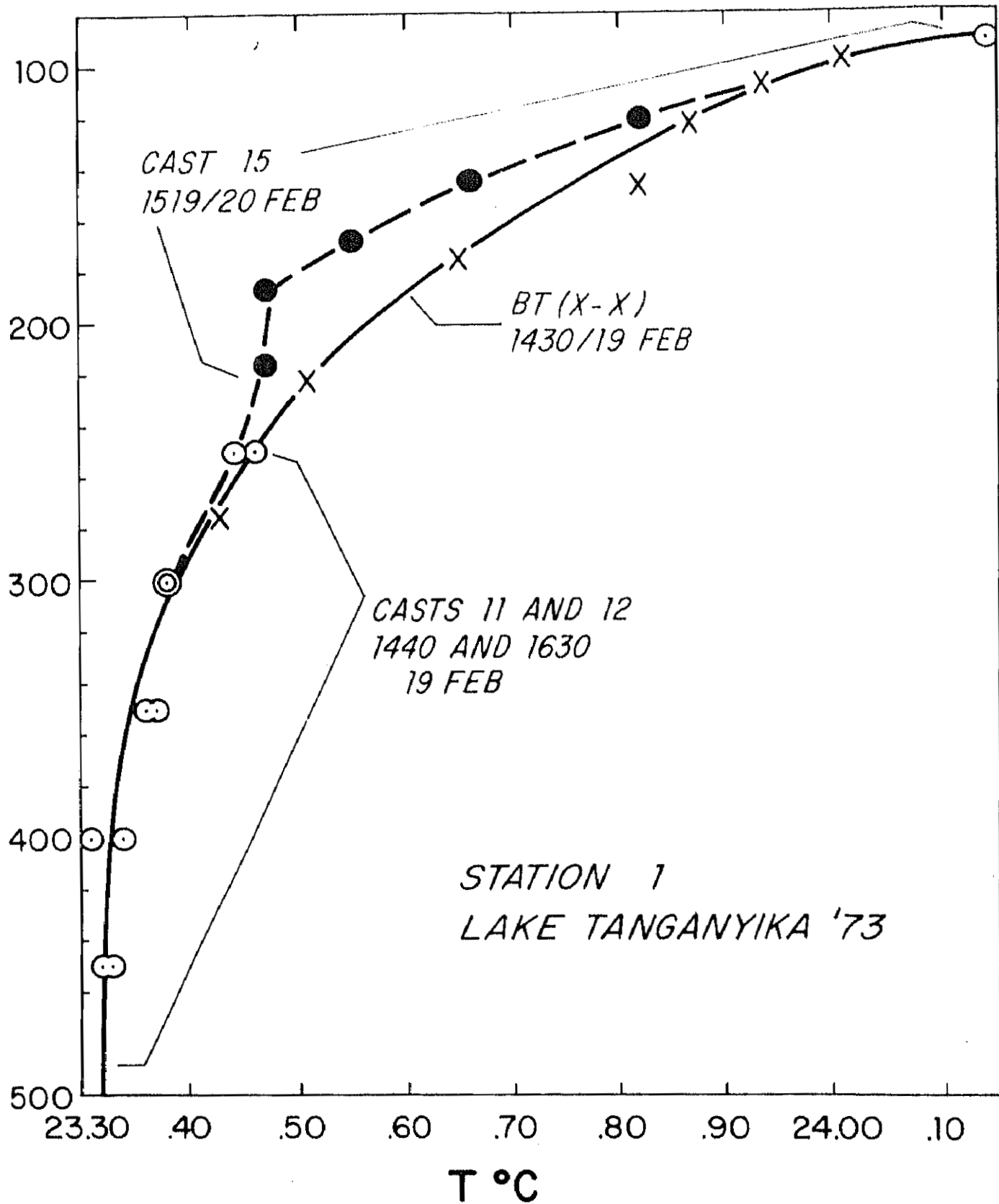Bottom depth = 1350m.

Figure 3. Temperature profiles at Station 1, 100-500m, together with the BT record (X-X-X) made just prior to Casts 11 and 12. The systematic deviation of Cast 15, one day later, may represent an internal wave effect.

HYDROGRAPHIC DATA

STATION 1: "Kigoma Station"

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	TEMP (deg C)	CHLORIDE (ppm)
1-2	51	5	27.34	26.6
	52	27	27.14	26.6
	53	45	26.15	26.6
	54	63	24.82	27.2
	55	91	24.14	27.7
1-15	51	120	23.82	27.8
	52	144	23.66	27.9
	53	168	23.55	27.8
	54	187	23.47	28.0
	55	216	23.47	27.8
1-11, 12*	51	250	23.44, 23.46*	27.8
	52	300	23.38, 23.38	27.9
	53	350	23.37, 23.36	27.8
	54	400	23.31, 23.34	27.8
	55	450	23.33, 23.32	27.7
1-3	51	625	23.29	28.0
	52	721	23.30	27.8
	53	818	23.26	27.7
	54	867	23.25	27.6

*First temperature = Cast 11, second temperature = Cast 12.
 Chloride analyses done on samples from Cast 11.

HYDROGRAPHIC DATA

STATION 2: "Nyanza Station". 0200-0254/21 Feb.
Wire angle: 7°. Messenger: 0231 (Local)
Bottom depth: 480m

STATION-CAST	BOTTLE NUMBER	DEPTH (m)	TEMP* (deg C)	CHLORIDE (ppm)
2-1	51	5	27.7	26.5
	52	99	24.1	27.4
	53	218	23.6	28.0
	54	328		27.9
	55	447		27.7

STATION 3: "Kagongo Station". 0742-0846/21 Feb.
Wire angle: 5°. Messenger: 0833 (Local)
Bottom depth: 380 m

STATION-CAST	BOTTLE NUMBER	DEPTH (m)	TEMP* (deg C)	CHLORIDE (ppm)
3-1	51	12	27.4	26.4
	52	100	24.0	27.6
	53	179	23.6	28.2
	54	269	23.6	28.1
	55	359		27.9

*Temperatures interpolated from BT

HYDROGRAPHIC DATA

STATION 4: "Magara Station". 1418-1502/21 Feb.
Wire angle: 15°. Messenger: 1442 (Local)
Bottom depth: 308 m

STATION-CAST	BOTTLE NUMBER	DEPTH (m)	TEMP* (deg C)	CHLORIDE (ppm)
4-1	51	5	27.3	26.4
	52	72	24.3	27.2
	53	145	23.8	27.6
	54	217	23.5	28.0
	55	290	23.4	28.0

STATION 5: "Bujumbura Station". 1650-1716/21 Feb.
Wire angle: 15°. Messenger 1706 (Local)
Bottom depth: 210 m.

STATION-CAST	BOTTLE NUMBER	DEPTH (m)	TEMP* (deg C)	CHLORIDE (ppm)
5-1	51	5	27.2	26.4
	52	48	25.0	27.0
	53	97	24.0	27.7
	54	145	23.7	28.3
	55	193	23.6	28.2

*Temperatures interpolated from BT

CHLORIDE DATA: STATIONS A, B, C; RIVER SAMPLES

		CHLORIDE (ppm)
A.	Surface water, Kasanga	27.1
B.	Surface water, Kipili	27.0
C.	Surface water, Kibwesa	27.2

RIVER SAMPLES

1.	Ruzizi River	14.3
2.	Muzazi River	0.7
3.	Muzazi Tributary	Int.*
4.	Mutumba River	Int.*
5.	Ruzibazi River	Int.*
6.	Kagongo River	0.2
7.	Malagarazi River	14.0
8.	Lubugwe River	0.6
9.	Lufubu River	0.1

Collection dates: pp. 9, 10, Section II.

*Interference with amperometric titration by unknown component.

III-2. Total CO_2 and C^{13}/C^{12} Measurements

Samples for Total CO_2 (ΣCO_2) and C^{13} analysis were collected in 250 ml rea-gent bottles with greased T-S glass stoppers, poisoned with $HgCl_2$ solution, and sealed with heavy wide rubber bands. This is our standard shipboard technique. The samples were analyzed by stripping the CO_2 from an acidified sample and mea-suring the exsolved CO_2 by gas chromatography (Weiss and Craig, 1973). Aliquots of the remaining water were then stripped separately and that CO_2 was collected in a vacuum line for C^{13} analysis in the mass spectrometer. The C^{13} data are re-corded as delta values of the ratio $R = C^{13}/C^{12}$ relative to the Chicago PDB standard, in units of per mil:

$$\delta C^{13} \, (^o/oo) = (R/R_{std} - 1) \times 1000$$

The ΣCO_2 and C^{13} data from Stations 1 - 5 are tabulated in the accompanying table. Surface samples from Stations 2 to 5 were not collected because of lack of sampling bottles. The Station 1 profiles are plotted in Figure 4, together with the titration alkalinity profile tabulated by Edmond (Section IV) which is shown for comparison.

The total CO_2 profile at Station 1 is almost an exact analog of the ocean profile scaled-up by a factor of 3. Ocean surface water concentrations are about 1960 μM/kg, while deep water varies from about 2100 to 2300 in passing from the North Atlantic to the North Pacific Deep Water. The values from Station 2 - 5 indicate that the profiles are quite uniform, those in shallower areas simply following the upper part of the Station 1 profile. The total CO_2 values of Degens et al. (1971) are about 10% lower than the data shown here and exhibit a great

deal more scatter vertically and horizontally. There is a possible discontinuity in our Station 1 profile at 187 - 250 meters which closely resembles the temperature break shown in Figure 3 and probably is due to the same phenomenon.

The deep water is enriched in total CO_2 by about 16% relative to the surface mixed-layer, again also a close parallel to the oceans, where the enrichment ranges from 10 to 20% from the Atlantic to the Pacific. In the ocean this enrichment is due to in-situ dissolution of carbonate detritus as it falls through the water column, but as discussed below this is probably not the case in Lake Tanganyika.

The C^{13} profile at Station 1 (and Stations 2 to 5, which are quite similar) is very similar to oceanic C^{13} profiles, the values of the order of 0 to 1 per mil representing the general value of marine carbonate and limestones (Craig, 1970; Kroopnick, Weiss and Craig, 1972). The mixed-layer value, 1.45 per mil, is about the value expected for equilibrium with the atmosphere at the surface temperature. In the ocean this value is about +2.0 per mil. The C^{13} data show considerable scatter and may have a systematic error of the order of 0.1 to 0.2 per mil, possibly being too positive by this amount. This is due to the fact that the full samples were first analyzed for total CO_2, leaving an empty space in the bottle into which CO_2 exsolved from the samples. This effect was unexpected because the loss of CO_2 was considerably larger than is observed in the well-buffered ocean samples, and precluded running any replicates of the total CO_2 analyses. A maximum effect of 0.3 per mil enrichment in C^{13} was measured in bottles which had been sampled several times and reduced to half-full. The C^{13} data tabulated are only those measured on bottles opened once and 3/4 full, so that effect should be smaller and more-or-less constant and should not seriously affect the profile.

Below 300m, in the deep water or hypolimnion, the three profiles in Figure 4 are linear, suggesting a diffusive gradient in steady state. The total CO_2 data

linear from 300 to 867m, with a standard deviation of 0.15%; the samples were randomized before analysis, and this deviation is that expected from experience in seawater analyses in which the concentrations are three times lower and the precision on replicates is ±0.5%. The linear profiles suggest a diffusive "internal" steady state with a flux of CO_2 from the bottom (or at least from below 900m) with no significant in-situ dissolution in the water column below 300m. The same is true for C^{13}; although it is actually the product of delta and CO_2 concentration which is conservative, it can be shown that the deviation in linearity of δC^{13} in this case would be only 0.002 per mil, which is unobservable.

The C^{13} profile has a minimum at about 220 meters, indicating a source of carbon low in C^{13}, such as organic carbon which is always lower than carbonate in C^{13}. The increase in C^{13} toward the bottom indicates, in a diffusion model, a source of carbon very high in C^{13} because of the small concentration gradient in total CO_2.

Figure 5, a plot of δC^{13} vs. ΣCO_2, sums up the carbon balance in Lake Tanganyika. The mixed layer carbon is approximately in equilibrium with atmospheric CO_2. Below the mixed layer there is a linear mixing regime to 220 meters, which is the locus of a production zone of CO_2 with an isotopic composition $\delta = -11\ ^o/oo$. This is probably due to dissolution and oxidation of carbonate and organic carbon in about equal proportions (in the ocean the mean value of carbon produced by these processes in deep water is about -15 per mil, about 25% of the production being due to dissolution of carbonate). The oxygen source for production from organic matter should be nitrate which shows a sharp maximum at 100m and virtually vanishes below 200m (Kufferath, 1952; Degens et al, 1971). This production produced the minimum in δC^{13} and contributes to the convex-up shape of the total CO_2 and alkalinity profiles in this region.

In the hypolimnion, below 300m, the profiles must represent either a transi-

ent diffusive profile, probably at "internal" steady state (diffusion rapid vs. overall drift of the profile), with a remnant water mass with values ΣCO_2 = 6840, δC^{13} = +0.7 per mil at the bottom (1350m), or a pure diffusion profile with insignificant vertical advection and an approximately constant vertical diffusivity, and a flux of CO_2 from the bottom of the order of 40 $\mu M/cm^2$year. This upward flux has to be greater than production rate in the 220m zone in order to maintain the gradient. The profile between 300m and the bottom is then a pure mixing profile (see Figure 5).

The C^{13} delta value of the flux from the bottom is calculated to be +28 per mil, a value much heavier than any normal carbonate or terrestrial material. About the only process which could produce CO_2 so enriched in C^{13} would be the formation of CH_4 from CO_2 by a fermentation process; the carbon isotope fractionation between CH_4 and CO_2 is very large, so that the residual CO_2-bicarbonate pool would be highly enriched in C^{13}.

To sum up: the most likely model is that shown in Figure 5, with two production zones for CO_2: one centered at 220m, producing -11 per mil carbon by carbonate dissolution and oxidation of organic carbon, probably by reduction of nitrate, and a flux from the bottom of very heavy CO_2 + bicarbonate ions, enriched in C^{13} because of in-situ production of isotopically light methane by fermentation reactions. The other possibility is that the hypolimnion profile is a transient due to mixing with a relic water mass which at some previous stage had a C^{13} value of +0.7 per mil or somewhat heavier. One single measurement of C^{13} in interstitial water can decide between these alternatives, and it is planned to carry out such measurements during the forthcoming 1975 expedition.
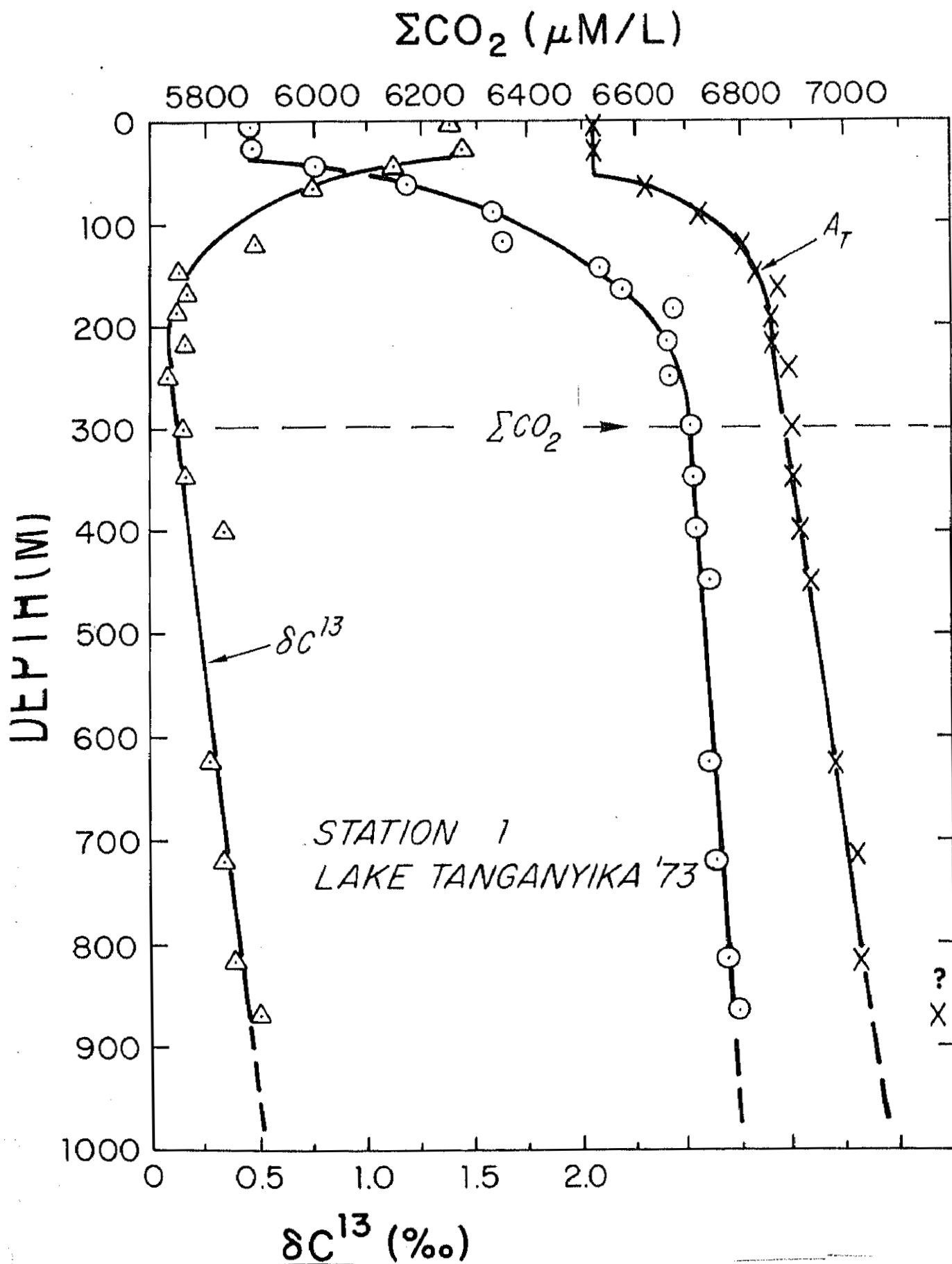
Figure 4. Profiles of total inorganic carbon (ΣCO_2), δC^{13}, and titration alkalinity (A_T) at Station 1
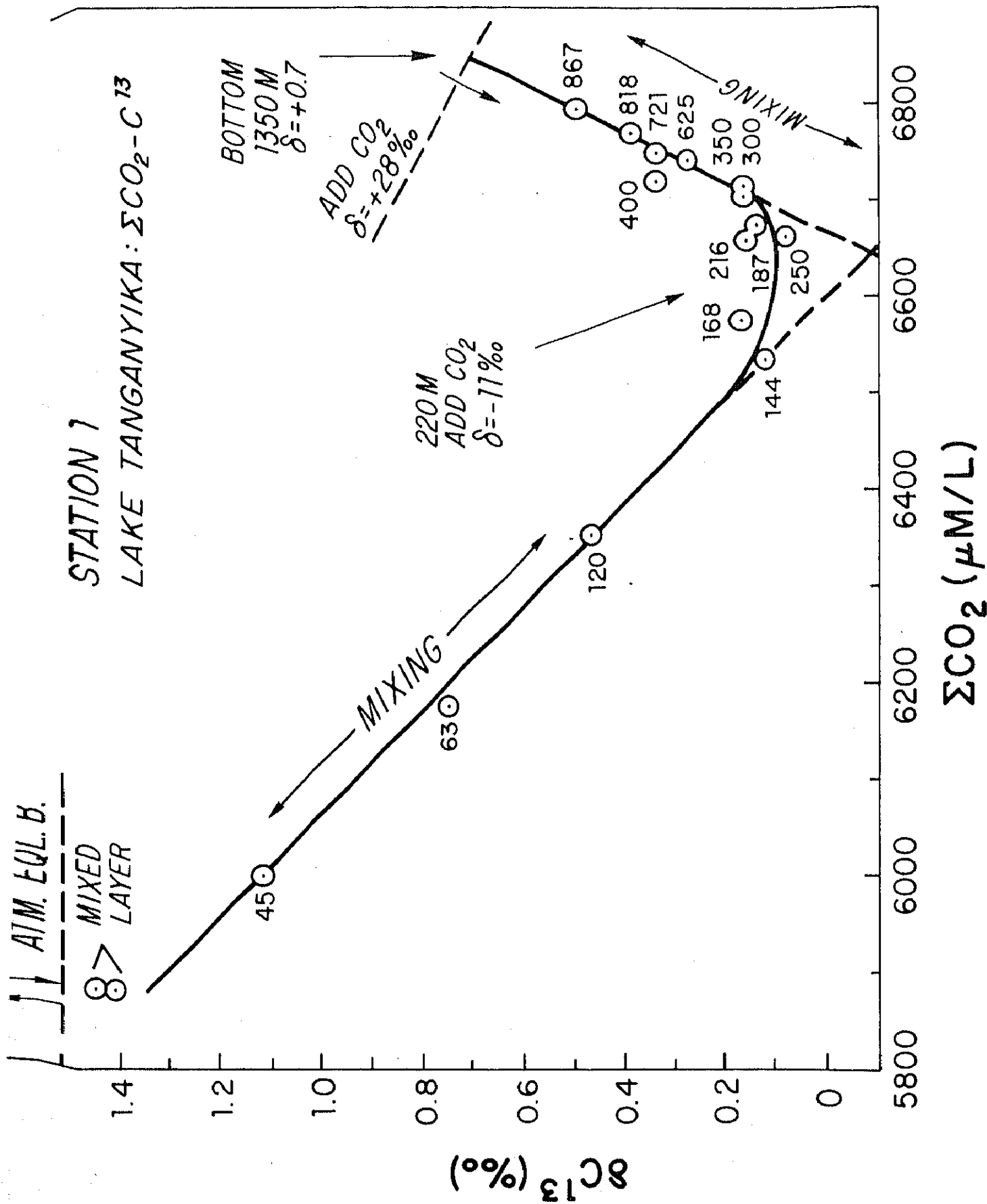
Figure 5. Total CO₂ vs. δC¹³ at Station 1

Lake Tanganyika 1973: Total CO_2 and δC^{13}

STATION 1: "Kigoma Stn."

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	ΣCO_2 μM/liter	δC^{13} ($^o/oo$) vs. PDB std.
1-2	51	5	5881	1.41
	52	27	5882	1.45
	53	45	6001	1.12
	54	63	6175	.75
	55	91	6335	–
1-15	51	120	6353	.47
	52	144	6536	.12
	53	168	6574	.17, .17
	54	187	6674	.14
	55	216	6660	.16
1-11	51	250	6665	.08
	52	300	6705	.16
	53	350	6714	.16
	54	400	6721	.34
	55	450	6741	–
1-3	51	625	6742	.27
	52	721	6749	.34
	53	818	6771	.39
	54	867	6795	.50

Total CO_2 and δC^{13}: Stations 2-5

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	ΣCO_2 μM/liter	δC^{13} ($^0/oo$) vs. PDB std.
2-1	51	5	5864	1.52
	52	99	6373	.36
	53	218	6614	.13
	54	328	6721	.18
	55	447	6735	.34
3-1	52	100	6460	.38
	53	179	6622	.23
	54	269	6659	.14
	55	359	6703	.27
4-1	52	72	6295	.63
	53	145	6481	.06, .07
	54	217	6679	.30
	55	290	6708	.30
5-1	52	48	6171	.85
	53	97	6425	.35
	54	145	6543	.29
	55	193	6710	.21

III - 3. Radium — 226 Measurements

Radium samples were collected at Station 1 in plastic 20-liter cubitainers, acidified to pH = 2 with nitric acid (containing a Pb carrier) and returned to the laboratory for analysis by measurements of its daughter Rn^{222}. The samples were transferred to glass bottles for radon growth and extraction, and the radon was measured in alpha-scintillation counters. The measurements were made by Dr. Y. Chung as described by Chung and Craig (1973). The measured radium activities are listed in the accompanying table and plotted in Figure 6. All samples were measured at least twice and the overall precision of the data is 3 to 4 percent.

The radium profile at Station 1 is very similar to oceanic profiles in Circumpolar Water south of the Antarctic Convergence, both in absolute values and the general uniformity of the profile. There is a one-point indication of a maximum at 100m where the nitrate maximum is observed (Kufferath, 1952) and the transition to anoxic water occurs, and this needs to be checked. Otherwise the profile in the mixed layer and Intermediate Water is uniform down to the top of the hypolimnion at 300m. Within the hypolimnion there is a definite increase with depth.

The convex-up profile is not consistent with a simple diffusive "internal" equilibrium in the hypolimnion for a "radioactive-conservative" component (no production or consumption except by radioactive decay) and a constant vertical diffusivity. In such a model, Ra^{226} with a radioactive mean-life of 2340 years would exhibit "concave-up" profiles to the left of the linear profile in Figure 6 for values of K (vertical diffusivity) less than 2 cm^2/sec (e.g. for K = 0.1, the Ra concentration at 600m = 19 dpm/100kg). The straight line is an "upper-limit" profile for a constant $K \geq 2$ cm^2/sec and no in-situ production of Ra by particulate dissolution (J=0). For $K \geq 2$ Ra is essentially a "stable-conservative" species.

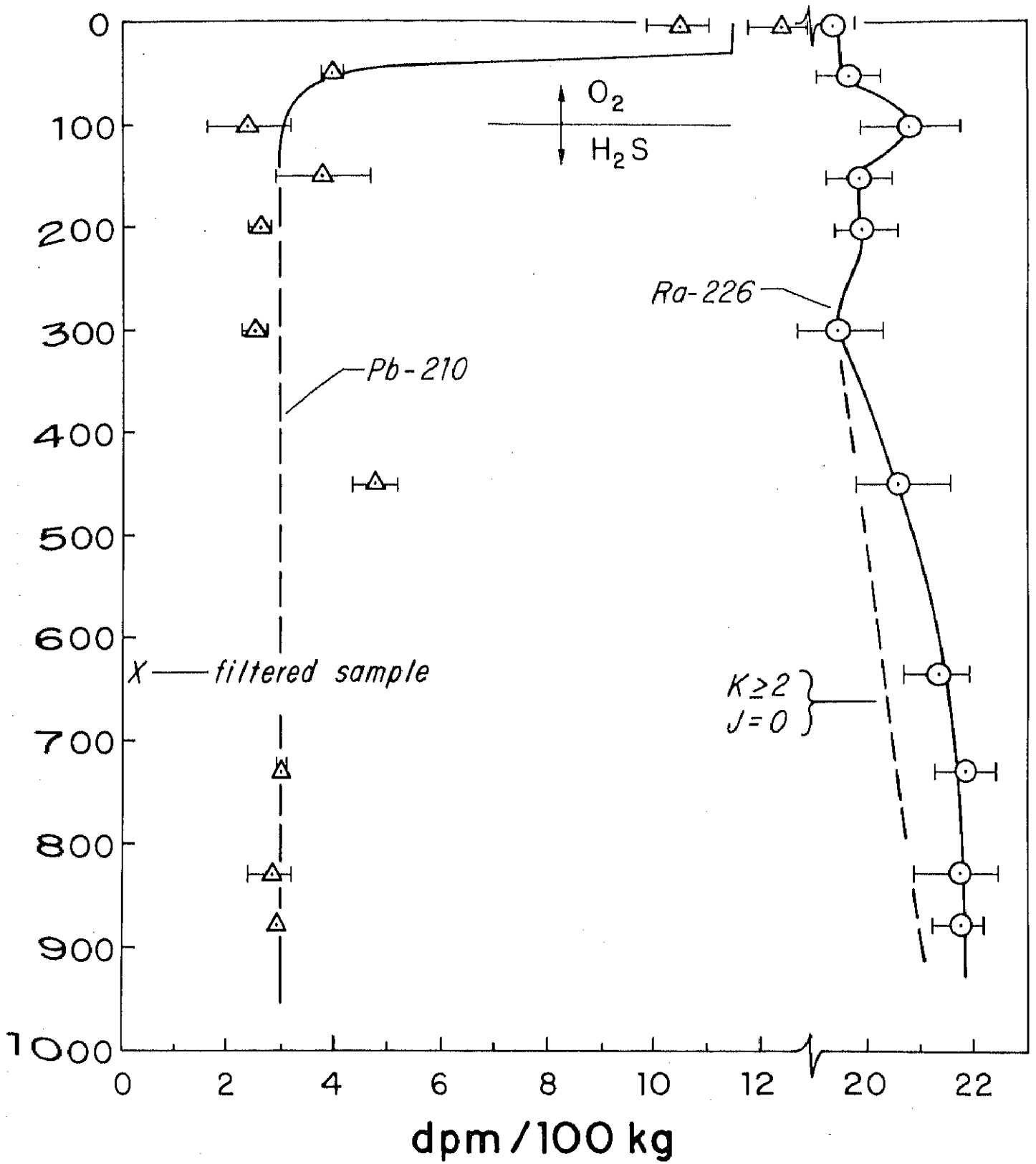Figure 6. Ra-226 and Pb-210 profiles at Station 1

Lake Tanganyika 1973: Radium-226 Profile
STATION 1

STATION -CAST -BOTTLE	DEPTH (m)	Ra^{226} ACTIVITY (dpm/100kg H_2O)*	AVERAGE**
1-19	0	19.7±.6, 19.1±.6	19.4±.4
1-4-53+	5	19.1±.6, 19.7±.6	19.4±.4
1-4-54+	50	19.3±.6, 20.2±.6	19.7±.6
1-4-55+	100	20.8±1.3, 20.8±.9	20.8±.9
1-16-51+	150	20.6±.9, 19.1±.6	19.9±.6
1-16-52+	200	20.4±.6, 19.5±.9	20.0±.6
1-12-52+	300	20.6±.9, 18.9±.9 18.9±.9, 19.5±.9	19.5±.8
1-12-55+	450	21.5±1.1, 19.7±.9 20.6±.6	20.6±.9
1-3-1	635	21.7±.9, 20.8±.9	21.3±.6
1-3-2	731	21.5±1.1, 22.1±.6	21.8±.6
1-3-3	828	21.5±1.3, 21.9±.9	21.7±.8
1-3-4	877	21.7±.6, 21.7±.6	21.7±.5

*1 dpm/100 kg H_2O = 0.461 × 10^{-14} g Ra/kg H_2O

**Errors: 1 std. dev. of replicates or counting error, whichever is larger.

RIVER SAMPLE

Ruzizi River, 15 February 1973: (9.2 kg sample)		23.9±1.4, 21.8±1.3	22.8±1.0

The observed profile thus requires, for a steady-state model, either a vertical diffusivity which _decreases_ upward from the bottom, or an _in-situ_ production of Ra within the water column (J>0). In this case the linearity of the total CO_2 profile implies that K is constant, CO_2 is conservative within the hypolimnion, but radium is non-conservative and there is an _in-situ_ production from dissolution of particulate material. On the other hand the profiles for one or the other, or both, of these two constituents may represent transient states within a relic hypolimnion. It is apparent, however, that detailed profiles of total CO_2 and Ra^{226}, with the addition of C^{14}, will be the most useful methods for study of the mixing regime within the hypolimnion.

III - 4. Lead-210

Lead-210 (radioactive mean-life 32 years) was measured on the radium samples after the Ra^{226} analyses were completed. In all but two cases carrier Pb was added at collection time as lead nitrate; in two cases carrier was added several months after the samples had arrived at the laboratory. In samples from the anoxic water, carrier Pb precipitated immediately as PbS, but redissolved on the way to the laboratory as the H_2S was removed by reaction with oxygen. The Pb^{210} analyses were made at SIO by Mr. M. Applequist, following the method described by Craig, Somayajulu, and Krishnaswami (1973). The samples were each purified twice, counted twice, and the results were corrected for growth of Pb^{210} from Ra^{226} during storage (this correction ranged from 4 to 25%). The final results together with one-sigma errors are given in the accompanying table and plotted in Figure 6 beside the Ra^{226} profile. These data represent the _total_ of soluble plus particulate Pb^{210}, except in the case of the 635m sample which was filtered before analysis.

In a closed system at radioactive steady-state, the Pb^{210} and Ra^{226} activities in Figure 6 will be equal, but in an open system in which lead is removed by some scavenging mechanism and exchange by mixing is unimportant, the activity ratio Pb^{210}/Ra^{226} is simply given by $(\tau_s/\tau_s + 32)$ where τ_s is the "scavenging residence time" for Pb (years), i.e. reciprocal of the scavenging rate constant, and 32 years is the radioactive mean-life of Pb^{210}. Thus if Pb atoms remain in the system on an average of 608 years before being scavenged, the observed activity ratio will be 95%. In the deep ocean the observed activity ratio averages about 60%, so that Pb^{210} remains in the deep sea on an average of only 50 years before removal (Craig et al., 1973). These scavenging times are basic to understanding the build-up of heavy metals in aqueous systems as they are added to the environment by man's activities.

The activity ratios Pb^{210}/Ra^{226} are also tabulated with the Pb^{210} measurements. The mean ratio in the hypolimnion is 13.2%, which means that the residence time of Pb^{210} (and thus of stable lead) is only 5 years in the hypolimnion water. In this water soluble Pb should be present principally as complexes with carbonate and sulfide, and it is to be expected that because of the low solubility of lead (K_{SP} = 13 for carbonate, 27 for sulfide) the lead concentrations are very low. The surface Pb^{210} activity is maintained at a high level, almost equal to the Ra activity, by atmospheric input of Pb^{210} derived from radon in continental air. This effect is also observed in the ocean. Below the surface there is a rapid transition to a uniform low Pb^{210} activity, and it appears that the 5-year scavenging time actually applies to the entire anoxic column below 100m.

The 625m sample was filtered immediately on collection through a 0.4 micron, 142mm diameter Nuclepore filter, which reduced the activity to 0.3 dpm/100kg. Although it thus appears that 90% of the lead in the system is in the suspended particulate matter, we cannot be sure of this for two reasons. The filtration

Lake Tanganyika 1973: Lead-210 Profile

Station 1 ("Kigoma")

STATION -CAST -BOTTLE	DEPTH (m)	Pb^{210} ACTIVITY $(dpm/100kg\ H_2O)^*$	Pb^{210}/Ra^{226} (0/00)	NOTES
1-19	0	10.5±0.6	54	No carrier when sampled
1-4-53+	5	12.4±0.6	64	
1-4-54+	50	4.0±0.2	20.3	
1-4-55+	100	2.4±0.8	11.5	
1-16-51+	150	3.8±0.9	19.1	No carrier when sampled
1-16-52+	200	2.6±0.2	13.0	
1-12-52+	300	2.5±0.2	12.8	
1-12-55+	450	4.8±0.4	23.3	
1-3-1	635	(0.3±0.1)	(1.4)	Filtered sample
1-3-2	731	3.0±0.1	13.8	
1-3-3	828	2.8±0.4	12.9	
1-3-4	877	2.9±0.1	13.4	

+Collected in 5-liter Niskin bottles at same depth on 4-5 casts; only the first collection is listed.

*Errors: one standard deviation

pump was contaminated with grease which may have removed some soluble Pb. Secondly, the filter may adsorb soluble Pb. We have determined that a single Nuclepore filter will adsorb only about 0.6% of soluble Pb in seawater, and about 2.6% in artificial Lake Tanganyika water made up without sulphide ions (based on initial counts on an experiment in progress). These effects are insignificant, but the presence of sulfide may introduce a larger adsorption effect and this has not been studied.

III - 5. Helium, He^3/He^4 Ratios

Samples of about 40cc were taken from the Niskin bottles into copper tubing and pinched off with steel clamps for dissolved gas measurements. The helium measurements were made by Dr. John Lupton at SIO. The gases were exsolved in a 1720-glass vacuum line and split into fractions which were sealed in 1720 breakseal tubes for subsequent analysis. The helium analyses were made on-line during the extraction procedure. He^3/He^4 analyses were made on a double-collecting helium isotope mass spectrometer; He^4 analyses were made on the same instrument by peak-height measurement. Atmospheric standards were interspersed for comparison in both cases; the resulting precision and accuracy are about 1%. The He^3/He^4 ratios were corrected for He^3 produced by radioactive decay of tritium during storage, using the data of Ostlund tabulated in Section V.

The measured concentrations and saturation anomalies for He^4, and the "ratio anomaly" and saturation anomaly for the rare isotope He^3 are tabulated in the accompanying table. (Since the He^3/He^4 ratio is of the order of 10^{-6}, He^4 and "total helium" are effectively synonyms). The saturation anomaly Δ, in percent, refers to the deviation from solubility equilibrium with atmospheric helium, at

the temperature of the sample and the atmospheric pressure at lake level, 773

meters (P = 693mm). The <u>ratio anomaly</u>, δHe^3 (percent) refers to the deviation

of the ratio He^3/He^4 from the atmospheric ratio 1.40×10^{-6}. At equilibrium this

ratio in dissolved He at lake temperature will be 1.38×10^{-6} because of a slight

preferential solubility of He^4, i.e. $\delta He^3 = -1.4\%$.

The He^4 concentration and He^3 ratio-anomaly profiles at Station 1 are plot-

ted in Figure 7. The surface values are in equilibrium with the atmosphere, but

below the mixed layer, the data show that helium is highly supersaturated, reach-

ing a maximum supersaturation of 126% (i.e. 2.26 x solubility) at a depth of

450m. This phenomenon is strikingly similar to the presence of "excess He" in

the deep oceans, although in the ocean, the maximum excess is only about 12%.

Also in the ocean, the excess He^4 concentration is accompanied by a mid-depth

maximum in the He^3 anomaly, due to injection of primordial He with a He^3/He^4 ra-

tio higher than atmospheric, along ridges such as the East Pacific Rise (Clarke,

Beg, and Craig, 1970). The Lake Tanganyika profile obviously shows the effects

of a similar mid-depth injection of helium, but here the He^3/He^4 ratio of the

injected helium is <u>less</u> than atmospheric, as shown by the minimum in the ratio

anomaly at the same depth ($\delta He^3 = -40\%$). The saturation anomaly for He^3 is 37%

at this depth because of the large excess in total helium.

In Figure 8, the concentrations of He^3 and He^4 are plotted vs. each other.

The linear relationship indicates a two-component mixture of atmospheric He and

helium with a 3/4 ratio of 3.85×10^{-7}, somewhat greater than the expected ratio

for "crustal helium" which ranges from 0.5 to 2×10^{-7}, the radiogenic produc-

tion ratio for average crustal rocks.

A possible injection site for helium at this depth is the area east of Ka-

lemie (aka Albertville) on the Zaire coast, where two heat-flow measurements of

R. Von Herzen indicate a substantially higher heat flow than in the rest of the

lake, located in the shift of the linear trend of the lake (probably a cross-graben fault) at about the required depth.

The linear plot in Figure 8 extrapolates to an initial He^4 concentration of 4.1×10^{-5} cc STP/kg (least-squares fit of all data except surface, and 828m which appears to be a gross error). If the 50 and 70m data are also removed because of the possibility that they are transitional from the seasonal 5m value, and the 175m point is eliminated as erroneous, the best-fit original concentration is 4.20×10^{-5}. These values, 4.1 and 4.2×10^{-5}, are taken as limiting original concentrations for the small plot of temperature vs. lake level at original saturation with helium, in the corner of Figure 8. The temperature limits indicated for original saturation are 4°C, and 23°C the present hypolimnion temperature.

This plot shows the relative position of the lake-level at original saturation required to give the observed helium solubility component, for any temperature at the time of last equilibration with the atmosphere. The present lake level (773m altitude) requires a saturation temperature of about 15°C, whereas if it is assumed that the hypolimnion has not warmed appreciably, and was saturated at 23°C, the required lake level is about 250 meters (150 to 350) below the present level. These data agree with the stable isotope measurements on the water, in indicating that the present hypolimnion is a relic of a colder, drier period of more intense evaporation and lower lake level. It should be noted that other gases such as Ar, not affected by injection of a non-atmospheric component will be more useful for such paleotemperature vs. paleolevel measurements.

Tritium and Helium 3

The tritium data measured by G. Ostlund at Miami, tabulated in Section V, are plotted in Figure 13. The data bracketed with a question-mark refer to the temperature discontinuity observed on this cast - a similar discontinuity appears to be present in the tritium data. Tritium in Lake Tanganyika is observable at least down to the hypolimnion, and the data appear to indicate a small but observable tritium gradient in the deep water. The upper water concentrations have been influenced by the large atmospheric tritium input due to nuclear weapons tests, and a detailed model of the input function will be constructed to model the penetration of this pulse into the lake, and the T–He^3 relationships.

The required He^3/He^4 ratio in the "injected component", namely 3.85×10^{-7}, may represent crustal helium enriched by decay of natural tritium. Total decay of 1 TU in water will produce 0.25×10^{-11} cc He^3/kg of water, so that total decay of 5 TU (± 1.5 for the range of crustal He ratio) in the water prior to emergence in the lake would give the required ratio. The earliest available tritium measurements (IAEA) for this region show 6 - 10 TU in rain at Entebbe in the early part of 1960, already affected by nuclear tests. It thus appears unlikely that the He^3/He^4 ratio derived for the injected component can be due entirely to tritium decay in injected meteoric water containing "average" crustal helium.
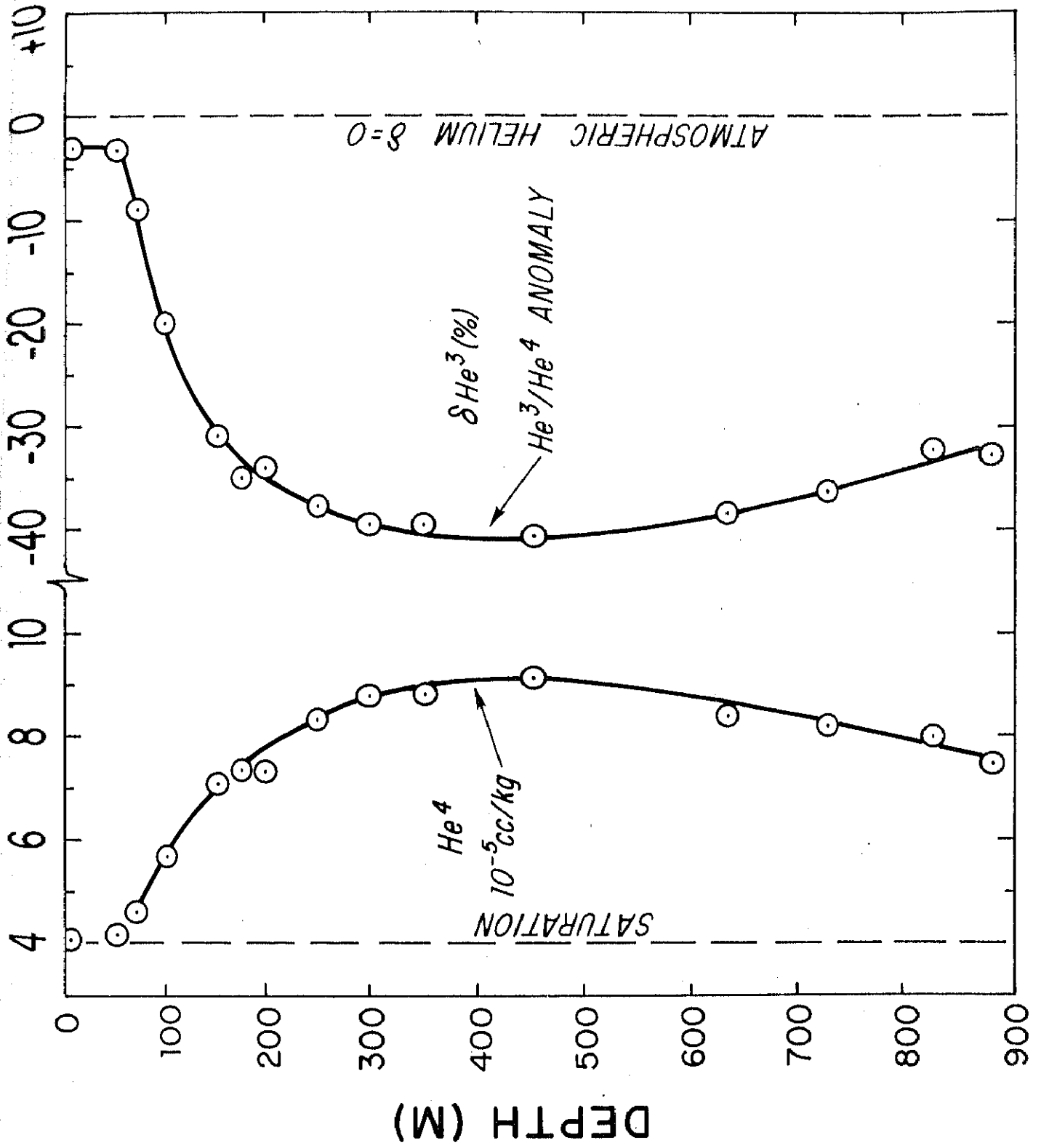
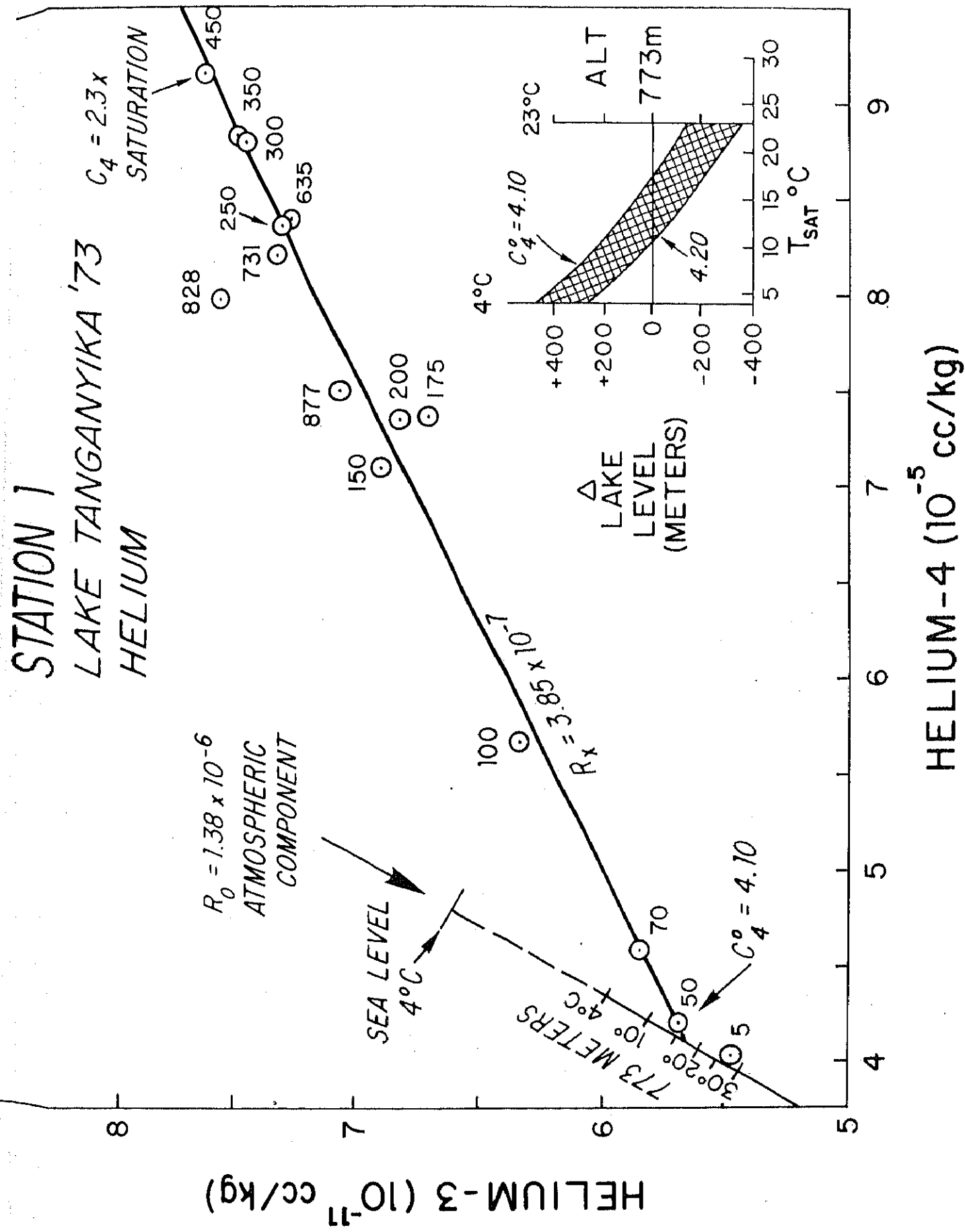Figure 7. He⁴ and He³/He⁴ ratio anomaly profiles at Station 1

Figure 8. He³ vs. He⁴ concentration plot: Station 1

Lake Tanganyika 1973: Helium 3 and 4 Profiles

STATION 1

STATION -CAST -BOTTLE	DEPTH (m)	He^4 (10^{-5}cc STP/kg)	ΔHe^4 (%)	δHe^3 (%)	ΔHe^3 (%)
1-4-53	5	4.03	+0.9	-3.1	-0.9
4-54	50	4.20	4.5	-3.3	2.5
18-51	70	4.58	13.6	-8.9	4.9
4-55	100	5.67	40.5	-20.1	13.9
18-53	150	7.10	75.8	-30.7	23.5
18-54	175	7.36	82.2	-34.9	20.3
18-55	200	7.35	81.9	-33.8	22.1
12-51	250	8.36	81.9	-37.6	22.1
12-52	300	8.80	117.7	-39.5	33.6
12-53	350	8.83	118.5	-39.5	34.1
12-55	450	9.15	126.3	-40.3	37.0
3-1	635	8.40	107.8	-38.1	30.4
3-2	731	8.21	103.1	-36.4	31.0
3-3	828	7.98	97.4	-32.3	35.5
3-4	877	7.50	85.5	-32.7	26.6

Δ = saturation anomaly (%) of He^3 and He^4, relative to 773m (P = 693mm).

$$\delta He^3 = [(He^3/He^4)/(He^3/He^4)_{Atm} -1] \times 100$$

$$(He^3/He^4)_{Atm} = 1.40 \times 10^{-6}$$

III - 6. Stable Isotopes: Deuterium and Oxygen-18

D/H and O^{18}/O^{16} ratio variations were measured by the usual methods (Craig, 1961); D/H was measured on hydrogen produced by reduction of water with hot uranium metal, and O^{18}/O^{16} variations were measured on CO_2 equilibrated with the water sample at 25°C. The variations in isotope ratio are given as delta values in per mil relative to the isotope standard SMOW (Standard Mean Ocean Water; Craig, 1961):

$$\delta \ (^{O}/oo) = (R/R_{SMOW} - 1) \ x \ 1000$$

where R is the ratio D/H or O^{18}/O^{16}.

The accompanying tables list the measurements for Stations 1 to 5; Surface Water Locations A, B, C; the river samples, and the time series measurements (to November, 1973) for Station 5 and the Ruzizi River inflow.

The deuterium and oxygen-18 profiles for Station 1 are shown in Figure 9. The lake is seen to be "isotopically upside-down", in the sense that the highest concentrations of the heavy isotopes are found in the deep water, rather than in the mixed layer. Because the heavy isotopes are concentrated by evaporation, the normal case for temperate lakes in the summer is the enrichment of heavy isotopes in the surface mixed layer, with isotopically "lighter" water in the hypolimnion due to mixing in winter with less-evaporated input water.

The normal precision of a single analysis is ±0.4 per mil for deuterium and ±0.04 per mil for O^{18}. However, the Station 1 profile samples were analyzed, on the average, in quadruplicate in order to obtain maximum sensitivity for the very small variations in the profile; the uncertainties in the profile data are no more than 0.2 and 0.02 per mil for D and O^{18} respectively. These profiles show the

same discontinuity in the region from 180 to 250 meters as shown by the temperature profile (Figure 3, Section III). In contrast to chloride, the isotopic gradients are well-developed to a depth of about 400m, and the O^{18} profile may show a very slight gradient still existing down to about 700 meters. On a $D-O^{18}$ plot, the profiles from all stations form a well-defined linear array below 60m depth, with slope of 6.8 and a standard deviation of the fit for D of about 0.1 per mil. From 300m to the bottom, the total D and O^{18} variations are about 0.2 and 0.03 per mil, so that one is working right at the precision limits within the hypolimnion.

Figure 10 shows the isotopic variations in the rivers compared to the lake data, and to the average or "world" precipitation line which marks the mean locus of unevaporated meteoric water, which has a slope of 8 and a D/H intercept of +10 per mil (Craig, 1961). A mean line connecting the river data with the lake surface water has a slope of 5.3, which is the typical slope resulting from evaporation of water (due to the kinetic isotopic effects in the diffusive evaporation process). The Ruzizi River data points, however, fall along a somewhat different line with slope, 6.2, reflecting the varying mixture with Lake Kivu surface water (which lies at the end of the arrow on the Ruzizi slope in Figure 10) and precipitation at the intersection of the Ruzizi line with the world precipitation line. This point is shown by the 13 November, 1973, Ruzizi sample, which contains at most only a very minor contribution from Lake Kivu (20% or less).

The range of Ruzizi River data represents the variation from maximum admixture with Lake Kivu surface water at the end of the dry period (September - October) to the maximum input of precipitation into the river during the rain-season peaks in November - December and March - April. It is important to note that the isotopic difference between Ruzizi water and Lake Tanganyika water is always large - this is probably the largest concentration difference between these two waters. Thus

the isotopic measurements should represent the best tracer for the depth to which inflowing river water sinks in the lake. Even in the case of the Ruzizi, which approaches most closely to the Lake water composition, a mixture of 2% river water should be observable in profiles. In Figure 9, the profiles at Station 5, the Bujumbura Station, have also been plotted, and one sees that at this time there was no significant concentration of Ruzizi water below the mixed layer, unless there is a thin layer between the sampled depths. Such measurements, supplemented by silica measurements in the times when the Ruzizi is significantly different from Lake water at about 100m, (i.e. in the rainy periods when silica is very high in the river), will eventually provide a direct answer to the depth to which the lake is influenced by inflowing river water.

The isotopic data show quite clearly that the water in the hypolimnion is the product of a time of greater evaporation than at present. There is at the present time no inflowing water as enriched in deuterium and oxygen-18 as the deep water, or as high in chloride. The deep water is the product of a drier, colder regime of higher evaporation, and it is not possible to account for the low temperature by sporadic input of cold river water or rain showers, as has been proposed, because such waters do not contain enough deuterium, oxygen-18, or chloride to account for the concentrations in the hypolimnion. However, as noted in the discussion of the chloride data, the isotopic and chloride concentrations in the deep water may represent a long-term steady state with surface water concentrations which fluctuate around the deep water mean values, depending on the lake level and the outflow through the Lukuga River to the Congo. That is, the deep water is a "relic hypolimnion" relative to the present sources of water, but whether it represents a time of much lower level (as indicated by the helium data) and lower temperature, or whether the isotopic and chloride concentrations (but not the temperature) match the mean surface water concentrations over, say, the past century, are questions which are not yet answered.

Stable isotope and chloride measurements from the weekly collections of surface water at Station 5 ("Bujumbura Station") and the Ruzizi River mouth are tabulated on pp. 61 and 62, through 13 November 1973, when the Ruzizi reached its lowest concentrations of deuterium and oxygen-18. The chloride concentration at this time was 9.5 ppm, the lowest concentration observed in the Ruzizi, and about half the highest values, observed in September (18 to 19 ppm). Although the general decline in chloride level at the onset of the rains in early November coincides with the decrease in D and O^{18} in the river water at this time, the Ruzizi also shows large oscillations in the chloride level at earlier dates with extreme low values on September 26 and October 23 which do not correlate with isotopic changes. These chloride minima probably represent input of highly-evaporated precipitation during the dry season, i.e. precipitation which does not differ greatly from the Ruzizi in isotopic composition, but is much lower in chloride. Thus the isotopic and chloride relationships allow one to distinguish three components of the river water: wet-season precipitation, dry-season precipitation, and Lake Kivu surface water.

Variations in surface water at Station 5 are very small over this period: 1 per mil for D, 0.2 per mil for O^{18}, and only 1 ppm for Cl. These variations correlate rather well, and show a maximum evaporation/input ratio in October - November, just before the onset of the rains is shown by the Ruzizi data.
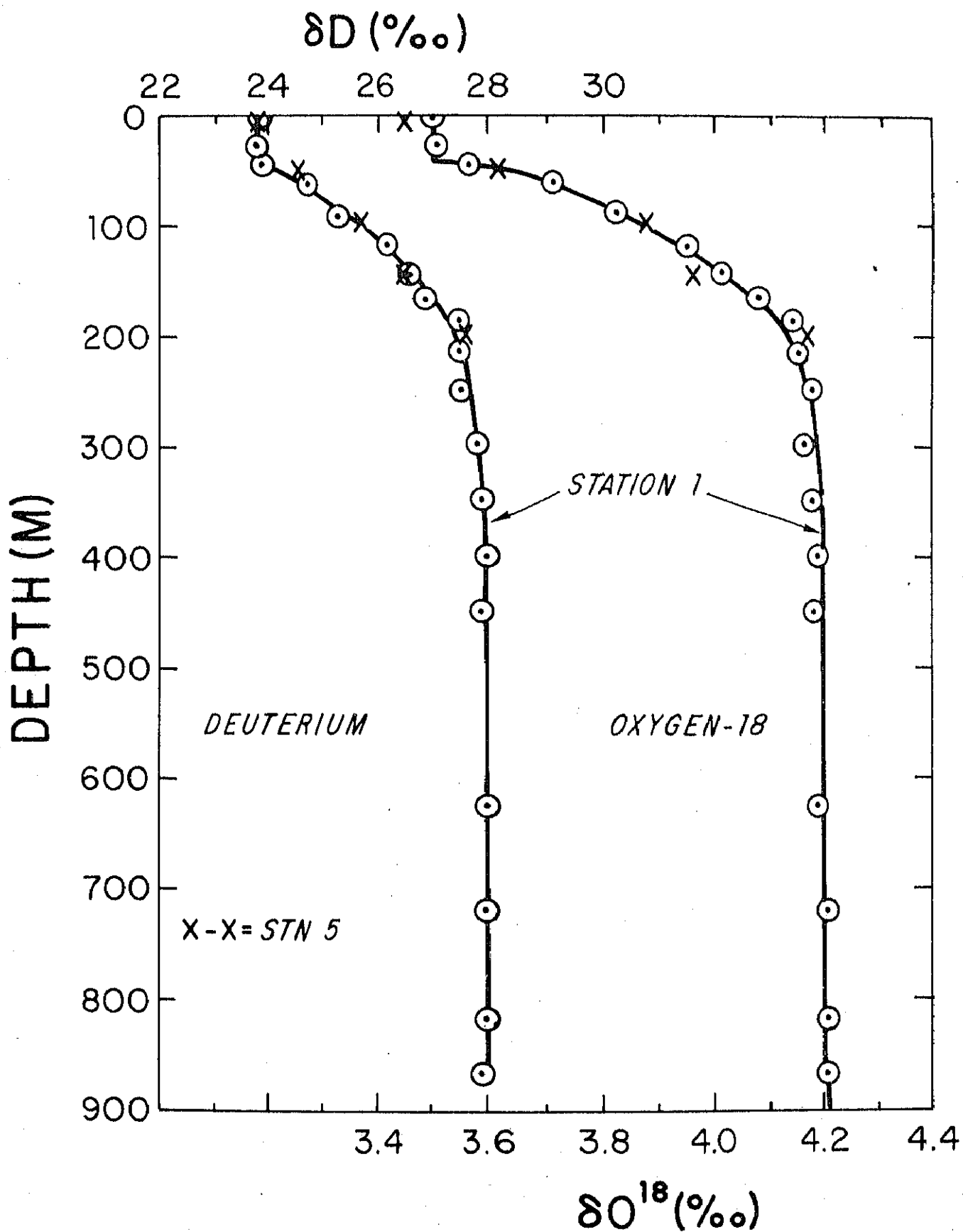
Figure 9. Deuterium and oxygen-18 profiles: Stations 1 and 5
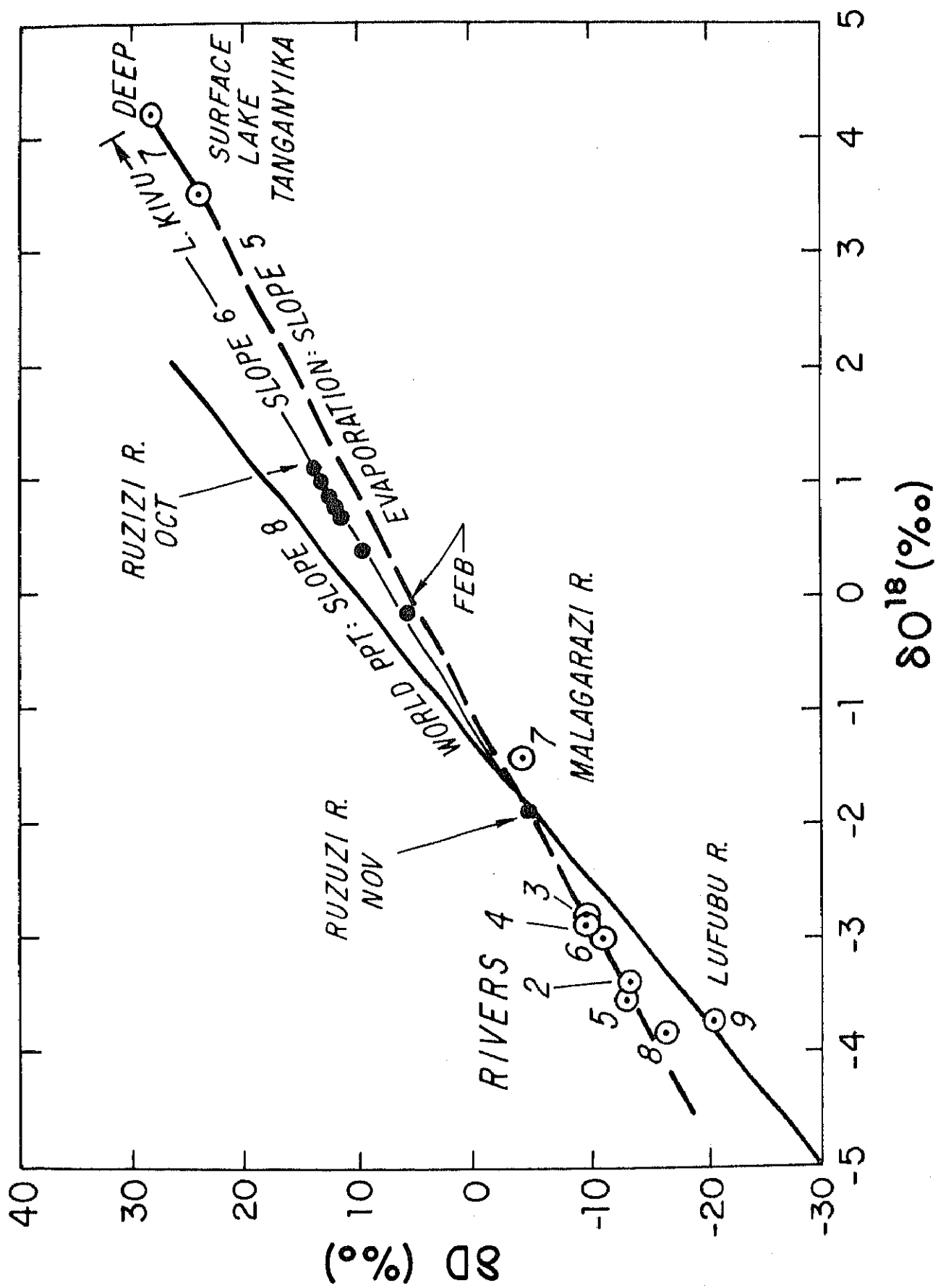
Figure 10. Deuterium vs. oxygen-18: Lake Tanganyika and Rivers

LAKE TANGANYIKA 1973:   Stable Isotope Data*

STATION 1:   "Kigoma Station"

STATION –CAST	BOTTLE NUMBER	DEPTH (m)	δD (°/oo)	δO^{18} (°/oo)
1-2	51	5	23.8	3.50
	52	27	23.8	3.51
	53	45	23.9	3.57
	54	63	24.7	3.71
	55	91	25.3	3.82
1-15	51	120	26.2	3.95
	52	144	26.6	4.01
	53	168	26.9	4.08
	54	187	27.5	4.14
	55	216	27.5	4.15
1-11	51	250	27.5	4.18
	52	300	27.8	4.16
	53	350	27.9	4.18
	54	400	28.0	4.19
	55	450	27.9	4.18
1-3	51	625	28.0	4.19
	52	721	28.0	4.21
	53	818	28.0	4.21
	54	867	27.9	4.21

*Delta values vs. Standard Mean Ocean Water (SMOW).

STABLE ISOTOPE DATA

STATION 2: "Nyanza Station"

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	δD (^{o}/oo)	δO^{18} (^{o}/oo)
2-1	51	5	23.5	3.52
	52	99	26.1	3.80
	53	218	27.6	4.14
	54	328	27.8	4.16
	55	447	27.9	4.20

STATION 3: "Kagongo Station"

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	δD (^{o}/oo)	δO^{18} (^{o}/oo)
3-1	51	12	23.7	3.26
	52	100	26.2	3.96
	53	179	27.1	4.08
	54	269	27.2	4.17
	55	359	27.9	4.18

STABLE ISOTOPE DATA

STATION 4: "Magara Station"

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	δD (^{o}/oo)	δO^{18} (^{o}/oo)
4-1	51	5	23.7	3.48
	52	72	24.7	3.69
	53	145	26.6	4.02
	54	217	27.1	4.12
	55	290	27.7	4.17

STATION 5: "Bujumbura Station"

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	δD (^{o}/oo)	δO^{18} (^{o}/oo)
5-1	51	5	23.8	3.45
	52	48	24.5	3.62
	53	97	25.7	3.88
	54	145	26.5	3.96
	55	193	27.6	4.17

STABLE ISOTOPE DATA

STATIONS A, B, C; RIVER SAMPLES

Collection Dates: March, April, 1973 (cf. pp. 9, 10; Section II)

LOCATION	δD (^{o}/oo)	δO^{18} (^{o}/oo)
A. Surface water, Kasanga	23.8	3.48
B. Surface water, Kipili	24.1	3.52
C. Surface water, Kibwesa	24.1	3.50

RIVER SAMPLES

1. Ruzizi River	+5.7	−0.12
2. Muzazi River	−13.1	−3.38
3. Muzazi Tributary	−9.6	−2.83
4. Mutumba River	−9.1	−2.88
5. Ruzibazi River	−12.8	−3.52
6. Kagongo River	−10.7	−3.00
7. Malagarazi River	−4.3	−1.42
8. Lubugwe River	−16.3	−3.80
9. Lufubu River	−20.4	−3.72

STABLE ISOTOPES AND CHLORIDE

Lake Surface Water, Station 5 ("Bujumbura Stn.")

DATE	δD (^{o}/oo)	δO^{18} (^{o}/oo)	Cl (ppm)
1973			
Feb. 2/21	23.8	3.45	26.4
Aug. 8/21	23.8	3.50	25.9
Sept. 9/13	23.9	3.51	26.5
9/30	24.6	3.57	26.9
Oct. 10/8	24.6	3.56	26.5
10/16	24.7	3.62	26.8
10/23	24.6	3.66	26.8
10/29	24.7	3.64	26.6
Nov. 11/5	24.8	3.68	27.0
11/13	24.6	3.54	26.9

STABLE ISOTOPES AND CHLORIDE

Ruzizi River Inflow

DATE 1973: M/D	δD (^{o}/oo)	δO^{18} (^{o}/oo)	Cl (ppm)
Feb. 2/15	5.7	−0.12	14.3
Sept. 9/4	11.6	+0.70	18.9
9/13	13.5	1.03	18.2
9/26	12.5	0.86	11.8
Oct. 10/8	12.2	0.78	14.1
10/16	13.4	1.16	17.8
10/23	13.8	1.10	10.6
10/29	13.8	1.14	15.4
Nov. 11/5	9.7	0.38	11.4
11/13	−4.6	−1.90	9.5

III - 7. References: Section III

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SECTION IV

LAKE CHEMISTRY: MEASUREMENTS AT MIT

1. MAJOR IONS: Na, K, Mg, Ca, Alkalinity

2. NUTRIENTS: Silicate, Phosphate

3. TRACE ELEMENTS: Barium

J. Edmond

Massachusetts Institute
of Technology

IV. LAKE CHEMISTRY: Measurements at MIT

J. Edmond

The Lake Tanganyika 1973 chemical data show general agreement with pre-
viously reported values where available. For the major cations and alkalinity
the surface concentrations agree precisely with those of Kilham and Hickey (Lim-
nol. & Oceanog. 18, 934, 1973). However the pronounced decrease of calcium with
depth reported by Degens et al. (Naturwiss., 58, 229-241, 1971) is not observed.
The latter authors found a <u>decrease</u> of 75 x 10^{-6} moles/1 between the surface
and 1460 meters (from 175 to 100 x 10^{-6} moles/1, much lower concentrations than
reported here). Beauchamp (in Livingston, U.S.G.S. Prof. Pap., 440 - G, 1963)
found an <u>increase</u> of 80 x 10^{-6} moles/1 between the surface and 700m. The pro-
file reported here shows an increase of 60 x 10^{-6} moles/1; in the right direc-
tion but still not sufficient to balance the alkalinity increase.

It is a pleasure to acknowledge the assistance of Susan Humphris and David
Drummond in this work.

IV-1. MAJOR IONS: Sodium, Potassium, Magnesium, Calcium

Samples for major ion measurements were stored in polyethylene bottles and
returned to MIT for analysis. The major cations were determined by *atomic adsorp-*
tion analysis on a Perkin-Elmer Model 403. The data reported here are preliminary
and include only sodium, potassium, *magnesium and calcium for Station 1* and the
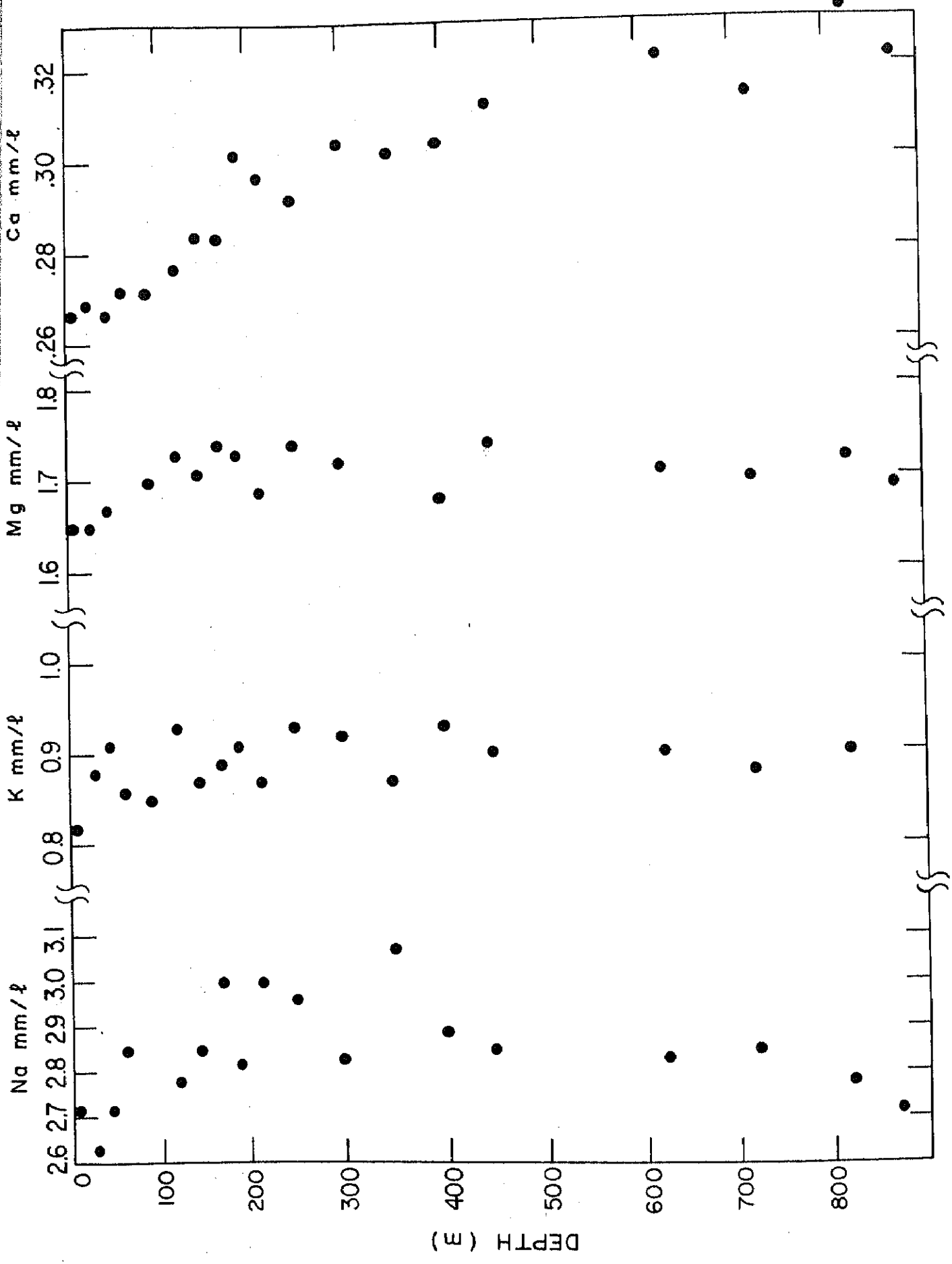river samples.

Figure 11. Major Ion profiles at Station 1

MAJOR ION DATA

1. Lake Tanganyika Profile, Station 1

STATION –CAST	BOTTLE NUMBER	DEPTH (m)	Units: 10^{-3} moles/liter			
			Na	K	Mg	Ca
1-2	51	5	2.72	0.82	1.65	0.267
	52	27	2.63	0.88	1.65	0.269
	53	45	2.72	0.91	1.67	0.267
	54	63	2.85	0.86	-----	0.272
	55	91	(3.98)	0.85	1.70	0.272
1-15	51	120	2.78	0.93	1.73	0.277
	52	144	2.85	0.87	1.71	0.284
	53	168	3.00	0.89	1.74	0.284
	54	187	2.82	0.91	1.73	0.302
	55	216	3.00	0.87	1.69	0.297
1-11	51	250	2.96	0.93	1.74	0.292
	52	300	2.83	0.92	1.72	0.304
	53	350	3.07	0.87	-----	0.302
	54	400	2.89	0.93	1.68	0.304
	55	450	2.85	0.90	1.74	0.312
1-3	51	625	2.83	0.90	1.71	0.322
	52	721	2.85	0.88	1.70	0.314
	53	818	2.78	0.90	1.72	0.332
	54	867	2.72	-----	1.69	0.322

MAJOR ION DATA

2.   River Samples*

Units: 10^{-3} moles/liter

		Na	K	Mg	Ca
1.	Ruzizi River	2.57	1.09	1.51	0.170
2.	Muzazi River	0.11	0.03	0.11	0.100
3.	Muzazi Tributary	0.10	0.02	0.11	0.096
4.	Mutumba River	0.17	0.04	0.17	0.116
5.	Ruzibazi River	0.04	0.02	0.06	0.086
6.	Kagongo River	0.12	0.02	0.16	0.110
7.	Malagarazi River	-----	0.04	0.21	-----
8.	Lubugwe River	0.48	0.04	0.65	-----
9.	Lufubu River	2.04	0.03	0.18	-----

*Collection dates February – April, 1973, as listed on p. 10, Section II.

IV-2. LAKE CHEMISTRY: NUTRIENTS – Phosphate, Silicate, Titration Alkalinity

Samples

Samples for silicate, alkalinity and trace elements were stored in polyethylene bottles. Samples for phosphate analysis were poisoned with mercuric chloride and stored in glass. The nutrient samples from Station 1 were hand-carried to MIT and run within five days of collection. The remainder were shipped to Dakar, transferred to the R/V Knorr and arrived in Cambridge (via Woods Hole) in the middle of April.

The data reported here are preliminary and include only phosphate and silicate for the lake samples and the rivers.

Methods

Phosphate and silicate were run, after suitable dilution with doubly distilled water, following the SIO "Cookbook", with a Beckman DU spectro-photometer.
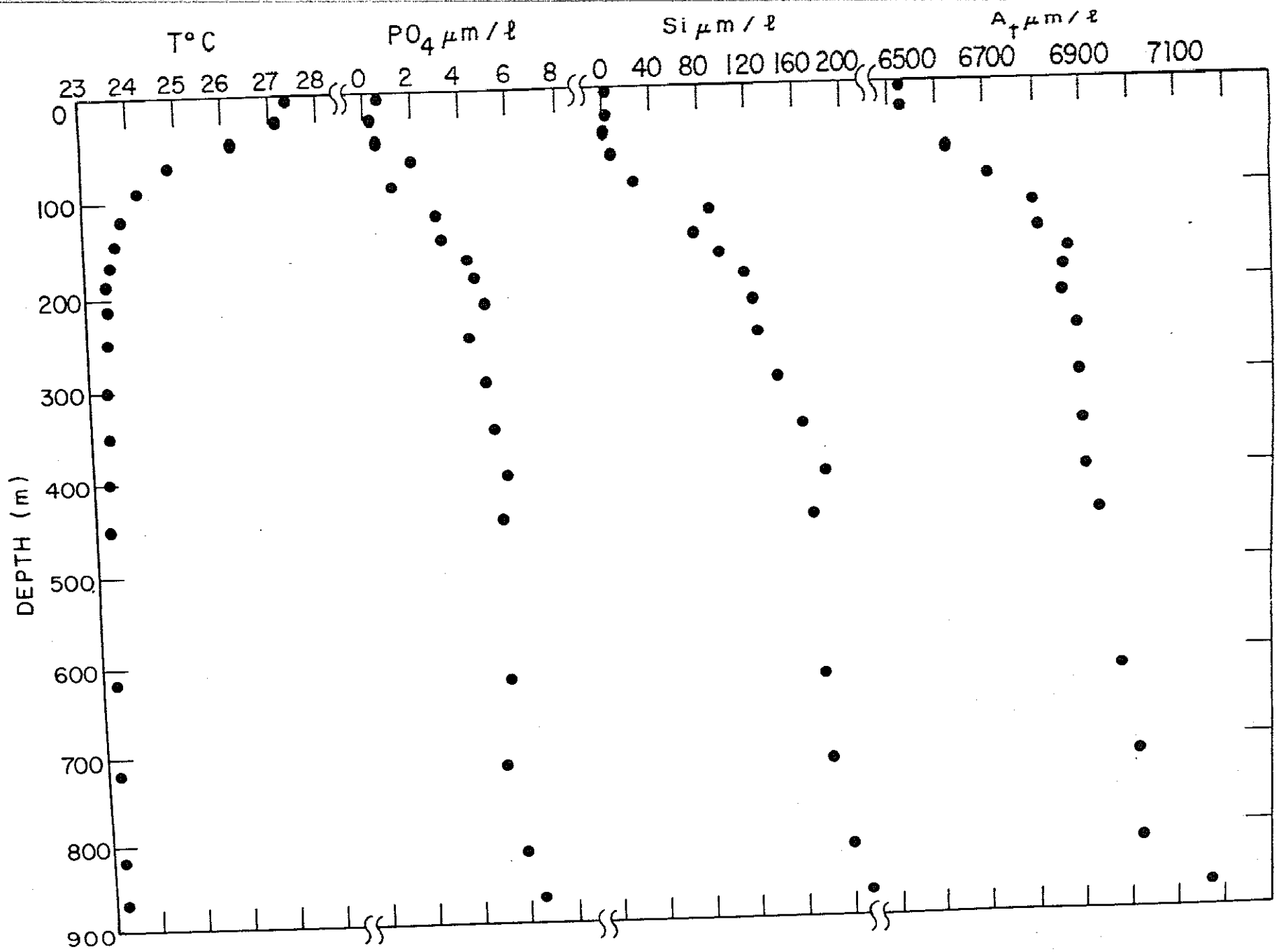
NUTRIENT DATA: 1. Lake Profile, Station 1*

UNITS: 10^{-6} moles/liter, 10^{-6} equiv./liter

STATION –CAST	BOTTLE NUMBER	DEPTH (m)	PO_4 µM/1	SiO_2 µM/1	A_t µEq/1
1-2	51	5	0.62	3.4	6521
	52	27	0.17	3.6	6525
	53	45	0.51	2.8	----
	54	63	1.98	8.2	6622
	55	91	1.07	25.8	6710
1-15	51	120	2.99	90.4	6804
	52	144	3.22	76.8	6815 .E
	53	168	4.18	97.2	6874
	54	187	4.46	115.4	6864 ?E
	55	216	4.86	123.8	6860
1-11	51	250	4.18	127.6	6893
	52	300	4.86	143.4	6895
	53	350	5.14	164.6	6901
	54	400	5.65	184.6	6911
	55	450	5.42	174.0	6935
1-3	51	625	5.54	180.6	6981
	52	721	5.14	185.2	7019
	53	818	5.99	199.2	7025 ?E
	54	867	6.67	216.0	7171

*Station 1 samples — hand carried to MIT

NUTRIENT DATA: 2. Lake Stations 2-5*

Units: 10^{-6} moles/liter

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	PO_4	SiO_2
2-1	51	5	0.75	44
	52	99	2.00	62
	53	218	4.20	120
	54	328	4.75	136
	55	447	5.80	144
3-1	51	12	0.50	46
	52	100	5.12	76
	53	179	4.10	106
	54	269	6.13	124
	55	359	4.67	130
4-1	51	5	0.75	44
	52	72	1.35	54
	53	145	3.95	84
	54	217	4.67	118
	55	290	5.15	92
5-1	51	5	0.60	36
	52	48	1.10	92
	53	97	5.67	70
	54	145	3.50	98
	55	193	4.40	126

*Samples returned by R/V KNORR

NUTRIENT DATA: 3. River Samples*

Units: 10^{-6} moles/liter

	PO_4	SiO_2
1. Ruzizi River	5.42	10.2
2. Muzazi River	0.11	160.6
3A. Muzazi Tributary A	0.00	190.6
3B. Muzazi Tributary B	0.06	191.6
4. Mutumba River	0.23	197.6
5. Ruzibazi River	0.06	105.6
6. Kagongo River	0.06	247.6
7. Malagarazi River	0.00	108.3
8. Lubugwe River	1.76	220.0
9. Lufubu River	0.18	96.4

*Collection dates February – April, 1973, as listed on p. 10, Section II.

NUTRIENT DATA: 4. Silicate in Lake Surface Water, Station 5
("Bujumbura Station") and Ruzizi River Inflow

LAKE COLLECTION DATE	Lake Surface, Stn. 5 SiO_2 µM/1	Ruzizi River SiO_2 µM/1	RIVER COLLECTION DATE
1973			
24 November	8.25		
15 December	6.30		
1974			
8 January	6.03	84	9 January
22 January	6.35	84	22 January
5 February	6.70	189 (?)	5 February
18 February	6.89	62	19 February
4 March	6.93	74	4 March
21 March	6.49	152	19 March
17 April	8.05	164	17 April
3 May	8.22	181	1 May
14 May	11.8	190	14 May
23 May	10.6	201	28 May

IV-3. LAKE CHEMISTRY: BARIUM (Station 1)

Barium samples were analyzed at MIT by isotope dilution mass spectrometry.

STATION -CAST	BOTTLE NUMBER	DEPTH (m)	Ba 10^{-9} mole/kg
1-10	52	5	500
1-6	52	45	502
1-11	51	250	636
	53	350	684
	55	450	715
1-3	1	635	781
	4	877	773
	4	877	768

SECTION V

UNIVERSITY OF MIAMI CONTRIBUTIONS

1. TRITIUM MEASUREMENTS: H. Gote Ostlund

2. ABSTRACT: The Equation of State of Lake Tanganyika
             By F. J. Millero

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TRITIUM LABORATORY

Data Release
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1973 LAKE TANGANYIKA TRITIUM SAMPLES

INTRODUCTION

Samples collected by H. Craig et al., on an expedition to Lake Tanganyika in April 1973. Stored in 500 ml glass bottles.

The residual samples have been discarded.

The collection bottles were baked and flushed with argon before use. Samples "A" and "B" represent two 500 ml bottles filled from the same Niskin bottle.

The analytical method is described by H. G. Ostlund et al., Earth and Planetary Science Letters 23, 69 (1974).

Tritium Units (TU): 1 TU = 10^{-18} atoms T/atom H.

The tritium profile is plotted in Figure 13. The question-mark brackets a possible discontinuity at 300m, which may be related to the temperature discontinuity in Figure 3, p. 25 (cf. p. 23).
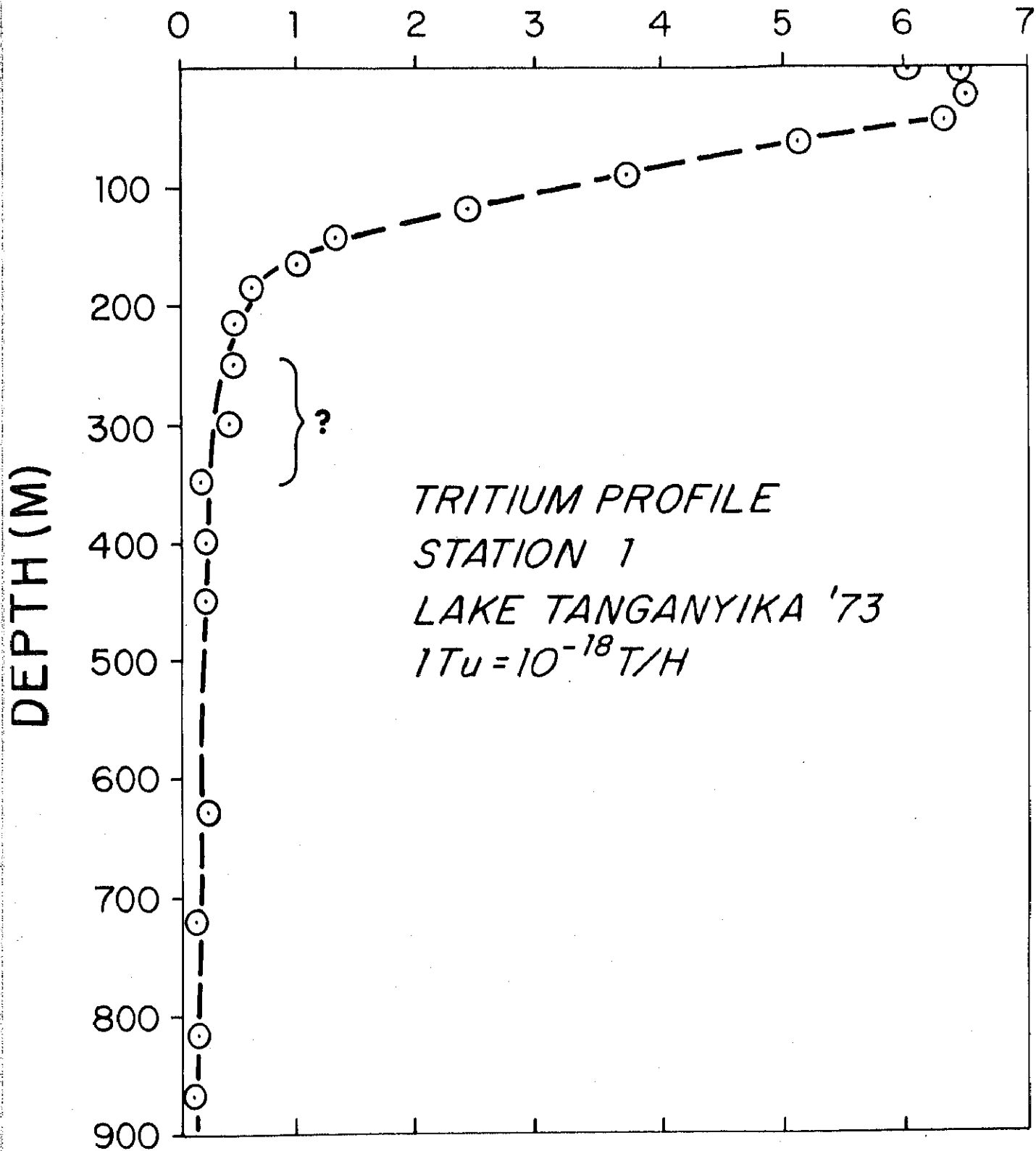
Figure 13. Tritium profile: Station 1

LAKE TANGANYIKA 1973: TRITIUM

STN	Lake Surface		Depth M	Run #	Trit. TU	Best Value
C.	Kibwesa		0	7260	6.56 ± .17	✓
B.	Kipili		0	4446	5.71 ± .16	✓
A.	Kisanga		0	2414	5.96 ± .17	✓
1.	1-2-51		5	4444	6.46 ± .15	✓
1.	1-17-52		5	2419	6.03 ± .17	✓
5.	5-1-51		5	1468	6.98 ± .18	✓
	Sounding		STATION 1 PROFILE			
	1-2-52	A	27	7258	6.47 ± .17	6.50 ± 0.15
		B	27	7250	6.53 ± .17	
	1-2-53	A	45	1474	6.47 ± .17	
		B	45	[4483	5.64 ± .15]	6.34 ± 0.15
		A + B		7352	6.21 ± .17	
	1-2-54	A	63	7254	4.91 ± .14	5.13 ± .15
		B	63	7285	5.37 ± .15	
	1-2-55	A	91	3446	3.57 ± .13	3.72 ± .13
		B	91	4485	3.88 ± .17	
	1-15-51	A	120	2434	2.36 ± .10	2.42 ± 0.09
		B	120	3489	2.48 ± .10	
	1-15-52	A	144	3487	1.37 ± .10	1.32 ± 0.08
		B	144	4472	1.26 ± .10	
	1-15-53	A	168	4491	1.06 ± .08	1.01 ± 0.08
		B	168	2454	0.95 ± .07	
	1-15-54	A	187	2447	0.55 ± .07	0.59 ± 0.08
		B	187	7276	0.63 ± .08	
	1-15-55	A	216	1507	0.49 ± .07	0.47 ± 0.07
		B	216	1496	0.46 ± .07	

STATION 1 PROFILE, (continued)

Sounding		Depth (M)	Run #	Trit. TU	Best Value
1-11-51	A	250	3481	0.42 ± .07	0.45 ± 0.07
	B	250	1500	0.49 ± .07	
1-11-52	A	300	3491	0.38 ± .08	0.40 ± 0.07
	B	300	1494	0.41 ± .06	
1-11-53	A	350	3475	0.14 ± .07	0.14 ± 0.07
	B	350	3473	0.14 ± .07	
1-11-54	A	400	7292	0.20 ± .08	0.20 ± 0.09
	B	400	3485	1.87 ± .09	
1-11-55	A	450	2434	0.28 ± .07	
	B	450	2445	0.08 ± .07	0.21 ± 0.07
			7353	0.29 ± .08	
1-3-51	A	625	4488	0.14 ± .07	0.24 ± 0.07
	B	625	4450	0.33 ± .07	
1-3-52	A	721	2412	0.12 ± .07	0.11 ± 0.07
	B	721	3469	0.11 ± .07	
1-3-53	A	818	3490	0.15 ± .07	0.13 ± 0.07
	B	818	2437	0.11 ± .07	
1-3-54	A	867	2453	0.04 ± .07	0.10 ± 0.07
	B	867	4469	0.17 ± .07	
			[7350	0.24 ± .12]	

RIVER SAMPLES: TRITIUM

Rivers		Date	Run #	Trit. TU
1.	Ruzizi R.	2/15/73	3451	13.2±0.3
2.	Muzazi R.	2/15/73	7256	14.0±0.3
6.	Kagongo R.	2/16/73	3449	12.3±0.3
7.	Malagarazi R.	4/3/73	4454	12.1±0.3
8.	Lubugwe R.	4/2/73	7244	17.2±0.4
9.	Lufubu R.	3/24/73	2416	14.2±0.4

Locations for the river samples and lake surface samples A, B, C, are given
on pp. 9, 10, and in Figure 1.

V - 2. <u>Abstract:</u> The Equation of State of Lake Tanganyika

The equation of state of Lake Tanganyika has been determined by using apparent molal volume data for the major ionic components of the lake. The PVT properties (P) of the Lake are of the form

$$P = P^\circ + A\ S(^\circ/oo) + B\ S(^\circ/oo)^{3/2}$$

where P° is the property of pure water, A is a constant related to the infinite dilution apparent equivalent property of lake salt (Φ°), B is related to the Debye-Huckel limiting law slope and $S(^\circ/oo)$ is the weight of the lake salts in parts per thousand. All of the PVT properties of the lake were found to be in excellent agreement with the properties of seawater (diluted with pure water) at the same total solid concentration or salinity. The densities agree to within ± 2 ppm, the expansibilities agree to within ± 0.6 ppm and the compressibilities agree to within ± 0.03 ppm from 0 to 30°C. From these calculations, it is clear that the PVT properties of Lake Tanganyika (as well as other lakes) can be determined from the equation of state of seawater diluted with pure water.

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