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CONFIDENTIAL

Oak Island Hydrogeology, Hydrography and Nearshore Morphology July-August 1995 Field Observations

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ABSTRACT

In July and August, 1995, the Woods Hole Oceanographic Institution conducted a combined hydrogeological, hydrographic, and nearshore morphologic investigation of Oak Island, Nova Scotia, to clarify some aspects of the geology and oceanography of Oak Island, related to the mysteries associated with the island. Using a combination of groundwater, dye tracer, acoustic imaging, pressure sensing, and pure geological observation, a number of conclusions were achieved. Radiocarbon analysis and scanning electron microscope (SEM) analysis clarified aspects of age dates on some vegetation samples from the island.

Major conclusions from the study include:

i) Borehole 10-x is weakly linked to boreholes around the Money Pit, including 24/8, and the 1993-series of five wells drilled by Atkinson and Group. The interconnection appears to be in deep anhydrite and gypsum bedrock at a depth of some 200' and more.

ii) Dye tests show no direct connection between 10-x and Smith's Cove or South Shore shorelines. Vast volumes of dye pumped with 400,000 gallons of water into borehole 10-x failed to make its way to the shoreline within a period of 3 days, in spite of use of sensing equipment with a detection limit of 1 part per billion (ppb).

iii) Tide gauges and piezometers installed in Mahone Bay as well as in 3 wells showed some tidal signature in borehole 10-x, but little tide in borehole 9303, and none in the Triton Shaft. In spite of the tidal signature in 10-x, no dye inserted into 10-x at 200' penetrated to the ocean within 3 days.

iv) Triton Shaft is not connected to 10-x or the Money Pit area hydraulically, to the depth of the Triton Shaft.

v) The sensitive dye-measuring fluorometer measured dye left from tests run in 1994 by Blankenship. However, no new dye from the present tests in borehole 10-x made it to the shoreline.

vi) Beach pits were dug along the shore with a backhoe. Buried peat deposits were found in two boreholes along the barrier beach on South Shore, separating the swamp from Mahone Bay. Radiocarbon dates to nearly 2000 years before present (ypb) indicate relative sea levels have risen approximately 0.4 feet per hundred years at the site. This is within the range of commonly accepted values for absolute global sea level rise.

vii) Implications of relative sea-level rise are that the shoreline of Oak Island was at a depth of 3-5' relative to the present shoreline, near 1000 AD.

viii) Radiocarbon age dates using Accelerator Mass Spectroscopy were determined on two wood samples from 10-x, one at a depth of 165', the second from an unknown depth (provenance: given to Oak Island Discoveries by D. Blankenship. Both samples are of modern age (within 100 ybp).

ix) Radiocarbon age dates of two "coconut" fibre samples were run. One sample was from D. Blankenship (via Oak Island Discoveries); it was dated at 765 ypb. The second sample was found in Smith's Cove by Dan Henskee and D. Aubrey; it was dated at about 1100 ypb. The provenance of the Smiths Cove sample is unclear (whether from original workers, searchers, or natural deposition at the coast from ocean currents). Additional research is taking place to clarify the possible origins of this old material.

x) Since no new boreholes or wells were drilled at the site, due to inadequate time for arranging logistics, the Pleistocene evolution of the island remains poorly known because of inadequate geological sampling and description of all previous boreholes.

xi) A further search plan is outlined for reducing level of uncertainties in several areas including origin of the island, human use of the island, and deep bedrock caverns and possible human artifacts contained therein.

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Introduction

Site Description

Oak Island is a small drumlin couplet at an elevation of about 40' above sea level, located within Mahone Bay some 40 miles southwest of Halifax, Nova Scotia. The island is some 3/4 mile from east-to--west, and some 1/2 mile wide from north-to-south. A swampy area with a beach at both north and sound ends separates the drumlins from one another. A causeway now links the island to the mainland community of Western Shore. On the eastern drumlin forming the Island, extensive exploration for buried treasure has been carried out since the late 18th century. Since two centuries of searches and borings have revealed little in the way of buried treasure, attention has been focused more on exploring early reports of the early searchers, and on determining likely human activity on the island prior to the 18th century.

Descriptions of activities on the island have been provided by numerous books on the Money Pit and the island itself (Harris, 1958, 1967). These books can be referenced for detailed descriptions of early activities of the searchers on the island.

Geological Evolution

Oak Island is located in a region noted for the presence of glacial landforms known as drumlins. During the last glaciation ending about 10,000 years before present, glaciers covered the area of Oak Island, retreating only some 18,000 years ago. Oak Island, along with many other islands off the coast of Nova Scotia, is a drumlin that was surrounded by sea water as sea level rose since the last major glaciation.

Drumlins are elliptical-to-elongated mounds composed of sediments known as till or lodgement till. Till deposition occurs when glaciers melt and their entrained sediments are left behind as a poorly sorted mix of grain sizes ranging from clay particles to large glacial erratics which can reach tens of feet in diameter. Till composition depends mainly on the parent material that contributed to the glacier's sediment load. The entrained sediments result from the physical weathering of the parent material by the glacial movement causing the abrasion of the rocks. Sediments in glacial till deposits are composed mainly of angular-to-subangular fragments resulting from these processes.

Though extensive research has been conducted on the processes responsible for drumlin formation, there is still debate as to whether drumlins result from glacial advance or retreat. Ground moraine deposits, which refer to basally deposited material, are often linked to drumlins. Many stream lined deposits composed of ground moraine are common. Drumlins are distinguished from these other deposits based on their consistent morphologies and their occurrence in large numbers together. They can often be observed in regions referred to as drumlin fields due to their dominance of the landscape. Drumlins are one of several geomorphic types associated with ice sheet deposition. From the location of a drumlin field in an area researchers can associate the different deposits in adjacent areas to determine the position of the ice sheet in the past. Drumlin fields usually occurred closer to the source of the ice sheet compared to features associated with the ice margins (outwash and fluted till deposits).

The actual mechanics of drumlin formation are greatly debated. One theory believes that a pressure gradient can be created beneath the moving ice because of the flow around an obstacle. As material passes this gradient, entrained material in the form of till will accumulate in this area of lower pressure. With time, more material will be deposited creating a larger pressure gradient, promoting the build-up of a streamlined form beneath the ice.

Eskers are coarse-grained stream deposits that may be associated with drumlins. Drumlins will have flowing water associated with them; this water may accumulate in a stream channel within the drumlin, concentrating coarse-grained stream lag deposits in a linear channel of high permeability. Eskers may or may not occur in any single drumlin. Their presence may be accompanied by flow features attributed by Oak Island searchers to "flood channels" if the esker extends to the ocean. Eskers might form high permeability, high flow channels with strong tidal influence.

Underlying the drumlins of Oak Island is a thick sequence of coarser, sandy material of thickness up to 50 feet. These coarser deposits may represent either beach deposits from previous low stands of sea level, or perhaps outwash material derived from the glacier and deposited prior to the till sequence, or even a coarser basal till from immediate ice-edge contact. Existing data are inadequate to specify the origin of these deposits, since extensive borings were not logged by a qualified geologist paying attention to the stratigraphic details. Either examination of existing samples (which we have been unable to locate) or new borings will be required to determine the origin of these coarse deposits.

Underlying the coarse sediment sequence is bedrock. The eastern drumlin (where the "Money Pit" is located) is located atop the Windsor Formation, comprised of limestone and dolomite inclusions in gypsum (and its anhydrous phase, anhydrite) strata, and sandstone. Sandstone was the original deposit in the Windsor formation, followed by anhydrite. Hydration of anhydrite by surface and groundwaters produces gypsum, the hydrated phase of calcium sulphate. Borings below the Money Pit area have brought up samples of anhydrite and gypsum, with some blocks of limestone and some sandstone. The limestone is the surface-most unit of the Windsor Formation in areas where the outcrops are better exposed. The gypsum has solution caverns, where ground-water or surface water has removed the calcium salts through solution. Below the Windsor Formation lies the Halifax Formation (belonging to the Meguma Group of Cambro-Ordovician age), of slate lithology. The thickness of the Windsor Formation is unclear, though it is thought to be less than 500' to 1000' within Mahone Bay. The western drumlin stratigraphy is not clear. Observations of slate have been recorded, which may indicate the western drumlin is underlain by the Meguma group rocks (Halifax Formation). This suggestion must be clarified by review of drill logs for the western drumlin area.

The contact between the westerly Halifax (??) Formation and the easterly Windsor Formation appears to be near the area of the "swamp" separating the twin drumlins. This contact may be either of two types: depositional or fault. If depositional, the Windsor Formation abuts the slate deposit of the Halifax Formation either continuously or discontinuously. We have too little information to specify the nature of the contact. If a fault contact, the underlying Halifax Formation may have an uplifted western arm, exposing the Windsor Formation sediments that may have existed on top of it to glacial erosion.

If this is a fault contact, the thickness of the Windsor Formation may be of roughly equal thickness over the eastern drumlin. If the contact is a depositional one, the thickness of the Windsor Formation would thicken to the east. The latter condition would open the possibility that caves, caverns, or other solution features at depth below the Money Pit may have at one time been accessible though the thinner, exposed sedimentary sequence near the swamp.

John Leslie, a Canadian geologist, provides a review of the geology of the region in the Oak Island Detection Program Documentation (1995). The Oak Island

Detection Program's Seismic Tomography also is consistent with the stratigraphic record presented here. however, as Mr. Leslie documents, lack of core samples available for review by trained geologists limits our ability to specify the nature of the glacial and pre-glacial deposits.

Since the deposition of the glacial deposits, sea level has risen. Accompanying sea-level rise has been erosion of the shoreline, migration of the shoreline inland, and reconfiguration of the island.

Past history of Oak Island Investigation

Numerous previous investigations have taken place on Oak Island in an attempt to determine the geology of the island, and to ascertain whether specific man-made features could be found on the island. Flood tunnels, man-made tunnel construction, drains, and other features have been reported on the island by previous searchers, yet their existence has not been documented well by scientific observation.

Most previous investigations have focused on the search for buried treasure, and potential clues about the human influence on the island have been lost due to the clumsiness of the search or the lack of concern over facts during the search. However, during the past two decades, some careful, engineering and scientific investigations have yielded some insight into the island evolution. In particular, the WHOI team focused attention on the following studies:

- Golder Associates, April, 1971. A detailed geotechnical investigation was undertaken by Golder Associates in 1970. Geotechnical borings, Archeological borings, dye testing, pumping tests, and laboratory tests were performed. Borings confirmed some 100 to 140 feet of clayey glacial till overlying more pervious sandy materials with large anhydrite boulders. The interface between the sandy stratum and the bedrock anhydrite is unclear from the borings. Solid anhydrite bedrock was encountered at depths of 220 to 240 feet below ground surface.

The borings encountered some geotechnical discontinuities in some borings, though the extent to which these were related to previous holes and searches is unclear. Groundwater near sea-level shows tidal fluctuations, though the magnitude and phasing of the tidal fluctuations was not quantified by accurate measurement. Groundwater itself was found to be generally about 4 to 6' above sea level. The Ghyben-Herzberg principle for groundwater, which assumes static equilibrium between the overlying freshwater and the underlying saltwater, indicates the freshwater lens is some 160- to 240- in thickness.

Dye testing did not show direct hydraulic communication between the Money Pit area and the ocean. Permeability of the lower pervious stratum (the sandy material) is high, with a permeability of about 0.01 cm/sec. However, it is not clear how strong the hydraulic connections are laterally within this stratum, though they are reported to be extensive. Dye was introduced into borehole 11A (24) at 198 foot level; borehole 102 in a pervious zone between 147 and 156'; in borehole 10 at a depth of about 189'; and into the Hedden Shaft at about 165'.

Tantalizingly, the Triton team found a 9' thick layer of loose sand and gravel between 147 and 156' in borehole 102. A 5.5 ft. thick zone of sand was found between 120' and 126' in Borehole 203. Finally, a 2.5 ft seam of sand underlain by 3.5 ft. thick cobble/boulder layer was encountered between 84 and 90' in Borehole 201.

Golder also reported Mr. Bowmaster as saying that the groundwater above depths of 160' to 180' were fresh, whereas groundwater in the lower portion of the boreholes, in the caverns, is generally saline.

Radio carbon dating of some wood samples from borehole 202 indicated wood from a depth of 125' was dated to about 18,000 ybp.

Hole 10-x was placed at the location of boreholes 202-203, where metal and wood was encountered during the Golder drilling (borehole 202).

Samples of pollen were sent to Dr. Ritchie of Dalhousie University, from depths generally of between 210 and 230'. No analyses were reported by Golder; results were sent directly to Triton. Three samples of wood from Boreholes 103, 202 and Smith's Cove were sent to Dr. J.J. Balatinecz of the University of Toronto. All three samples were reported to be Eastern spruce (White spruce, *Picea glauca*).

- Oak Island Detection Program: May, 1993 through May 1995. The most comprehensive and sophisticated of the investigations of Oak Island to date, the Detection Program was managed by Bob Atkinson, and carried out by numerous scientists from North America. The Detection Program included downhole electromagnetics, downhole magnetometry, surface magnetometry, water column analysis for gold and silver, enhancement of video images at the base of 10-x, and downhole seismic tomography. In order to carry out the program, five new holes to depths of 200-260' were drilled, and older holes were renovated. Unfortunately, Hole 10-x could not be cleared of the drill bar near 200', so 10-x was not part of the surveys.

This sophisticated detection program clarified aspects of the geology of the site; however, existing technology (hardware and software) was inadequate to improve resolution sufficiently to resolve the questions addressed (existence of man-made objects; existence of man-made tunnels; existence of treasure-trove). The image enhancement of videos from 10-x suggested some interesting possible features in the cavity found there, including tools, hewn logs, and so on. However, the enhancement was never definitive and attempts to get further photos at the base of 10-x were unsuccessful due to blockage of the hole.

- Warnock Hersey International Soils Investigation Report of 31 July and 5 November 1969. W-H installed a series of 10 boreholes in 1969. They also made periodic measurements of water table level, but at intervals which don't allow one to infer tidal variations.

Purpose of present investigation

The Woods Hole Oceanographic Institution team proposed the following tasks for their participation in unraveling the mysteries of Oak Island:

Task 1: Review existing information on Oak Island as provided by the Triton Group.

Task 2: Oversee drilling of up to four 6" diameter, perforated pvc-cased wells around the "money pit," to provide access for hydrogeological measurements.

Task 3: Install up to five pressure ('tide') gauges to monitor levels in wells (piezometers) and in the adjoining ocean, to estimate the degree of hydraulic connection between the wells themselves, and between individual wells and the adjoining ocean.

Task 4: Perform CTD measurements within the wells over tidal cycles, to determine if there are sources of water injected into the wells during the course of a rising tide. The CTD measurements will provide some indication as to the salt content and depth of such intrusions into the wells.

Task 5: Perform CTD and fluorometer measurements in the nearby waters to search for indications of freshwater flow from the island to the adjacent sea. The fluorometer will be used in dye tests in the well.

Task 6: Perform a detailed bathymetric and side-scan sonar survey of the region surrounding the island, to determine the surficial geology and to identify any anomalies as well as areas of seagrass beds.

Task 7: Dive on any anomalies that may be of interest to us that may aid in understanding the geology and groundwater flow from the island.

Task 8: Help perform beach surveys to find datable material in old structures exposed on the beach.

Task 9: Obtain up to 8 radiocarbon dates on carbonaceous material to determine dates of some features in or adjacent to the beaches.

Task 10: Provide a short written report summarizing the geology and hydrology of the island as clarified by this study, plus descriptions of geological anomalies found on the island.

Summary of approach

The WHOI program was directed towards observing the geological phenomena at Oak Island, and determining the likelihood that such observations could represent natural versus human-influenced processes. Previous observations of dye dispersal, underground (groundwater) fluid flow, offshore stone structures, and the like have been poorly documented scientifically; the present proposal was to provide scientific documentation of their existence or non-existence, and of their origin. This project was purely based on hydrology and oceanography, and provided no specific or original archeological (historic or pre-historic) or historical investigation.

We had less than one month to prepare for this field program, due to the protracted negotiations about scope of work. Thus, we were unable to fulfill all elements of the desired work in this time period.

Field Observation Program

The field observation program took place in July 1995 (see attachment A). Because of the short lead time of the field program, some tasks itemized above were not included in the program, including:

- Drilling new boreholes
- Dye studies in new, screened wells drilled for this purpose.

In spite of the lack of time to prepare for these two elements of the field program, the remainder of the goals of the project were attained. Briefly, the methods used for these different tasks were as follow:

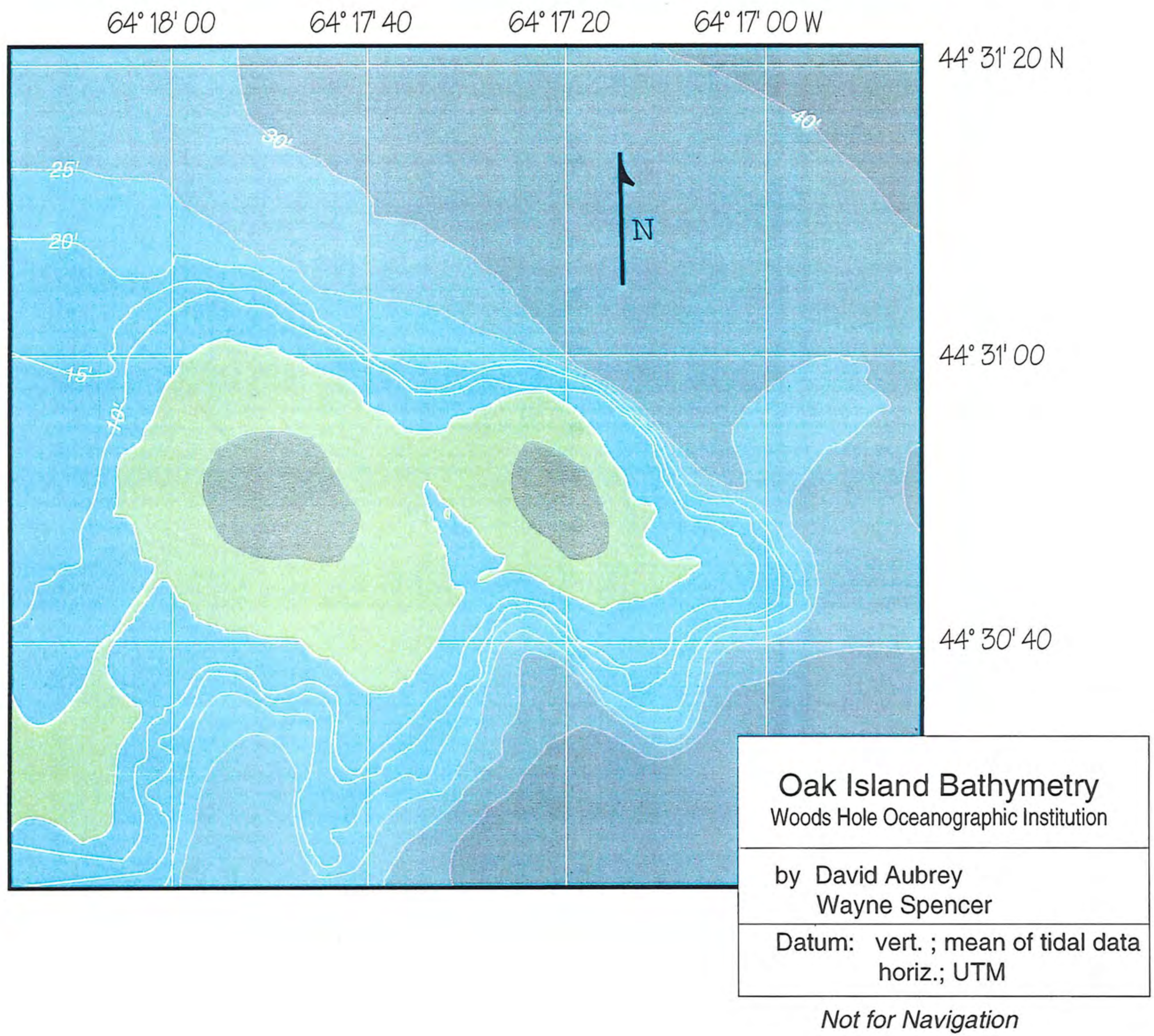
Bathymetry and side-scan sonar

A Klein 595 side-scan system was used to collect side-scan data. The 595 system is a dual frequency, high-resolution SONAR system that is able to record acoustic images of objects and shapes on the seafloor. The system was towed throughout the area of the south shore and Smith's Cove extensively. It was also towed around the entire Oak Island coast (up to the causeway) on two lines close to shore. Only two relatively insignificant returns were noted. One return was Northwest of Smith's Cove at latitude 44° 30' 55.0094", longitude 64° 17' 9.0641". The other return was Southwest of south shore at Latitude 44° 30' 19.1195", Longitude 64° 17' 24.1467". The one by south shore was a rectangle about 1 meter by 1.5 meter. The return by Smith's Cove (but completely out of Smith's Cove) consisted of a number of circular shapes (not uncommon to find in the coastal zone) 1 to 2 meters in diameter.

The bathymetry map (Fig. 1) presents sorted data that have been contoured. The data density for bathymetry is great as we recorded depth and position every 2-3 seconds during the 5-day period that we operated on the Blue Eagle. A full scale smooth sheet is available to show detailed bathymetry. The vertical datum is related to the mean of the 3-week tide data taken at the Oak Island Inn dock. The horizontal data are related to the UTM project in WGS 84 datum. The positioning for the survey vessel was accomplished with a differential global positioning system on board the Blue Eagle. An integrated navigation system (HyPack) logged the navigation information and the depth information. Depth was acquired using a dual-frequency Odom Echo-Track, survey-quality fathometer. Data were reduced at the laboratory using HyPack software, and tracklines, bathymetric maps, and time charts were plotted.

CTD observations in boreholes

A Sea-Bird SeaBird Conductivity, Temperature, Depth (CTD) was lowered into several boreholes to determine the depth of the wells, the salt content, and the temperature (for correcting conductivity to salinity). CTD observations were made by lowering the CTD from the surface to the bottom of the hole on a line, with the CTD recording a data point continuously on internal memory once a second. Since


64° 18' 00
64° 17' 40
64° 17' 20
64° 17' 00 W
44° 31' 20 N
44° 31' 00
44° 30' 40
N
40'
30'
25'
20'
15'
10'
Oak Island Bathymetry
Woods Hole Oceanographic Institution
by David Aubrey
Wayne Spencer
Datum: vert. ; mean of tidal data
horiz.; UTM
Not for Navigation

the CTD recorded temperature and conductivity, salinity could be calculated using well-known algorithms. Pressure measurements on the CTD allowed calculation of the sample depth at which the measurements were taken. CTD casts were taken in boreholes 10x, A (pumping shaft, to the NE of 10x), Triton, 9305, and 24/8 (See Tables 1 and 2 for details of sampling times and locations of wells).

TABLE 1
Relative elevations of well-heads
(survey of 28 July 1995)

Well ID	Relative elevation	Latitude (N)	Longitude (W)
24/8 (datum)	0.00'	44°30.771'	64°17.305'
9301	0.5'	44°30.799'	64°17.305'
9302	0.7'	44°30.776'	64°17.317'
9303	0.02'	44°30.779'	64°17.305'
9304	0.12'	44°30.778'	64°17.320'
9305	0.66'	44°30.771'	64°17.307'
A1		44°30.890'	64°17.208'
B1		44°30.805'	64°17.274'
Pumping shaft (A)		44°30.806'	64°17.273'
600' shaft		44°30.825'	64°17.283'
Triton***		44°30.887'	64°17.296'
10-x	17.38'	44°30.785'	64°17.279'

*** Due to building blocking GPS signal, location was taken on lone large rock 11 paces west of shaft.

Tide gauges/piezometer observations

In order to determine the degree of connectivity of the boreholes to marine waters, deployed tide gauges/piezometers in four locations: Pier at Chester Harbor (ocean gauge); 9303, 10x, and Triton Shaft (see Table 3). Previous searchers and investigators have noted tidal fluctuations in the well waters, but the extent of the fluctuations have not been quantified by accurate continuous measurement.

TABLE 2

CTD CASTS OAK I. 7/24/95

CTD WELL LOG OAK ISLAND JULY 24, 1995
CTD DELAYED AT SURFACE FOR 20 SECONDS BEFORE LOWERING

WELL LOCATION	CAST NUMBER	ATLANTIC TIME SWITCH ON	ATLANTIC TIME SWITCH OFF	SALINITY AT ONE METER	SALINITY AT BOTTOM OF CAST	REMARKS
10X	0	7:26:55	7:31:05	0.5825	16.2987	
A	1	7:46:35	7:51:55	0.3695	20.2626	
TRITON	2	8:07:00	8:10:55	0.0566	0.0476	
NO CAST	3					
10X	4	8:26:55	8:32:50	0.5719	0.5689	
A	5	8:46:35	8:52:52	0.3879	19.2947	
TRITON	6	8:59:00	9:02:49	0.0531	0.0477	TWO DROPS DUE TO HANG-UP ON LEDGE
10X	7	9:26:55	9:31:24	0.5717	3.0553	
A	8	9:35:40	9:40:04	0.3871	12.3902	
TRITON	9	9:47:30	9:50:40	0.0532	0.0476	SEVERAL HANG-UP'S ON WAY DOWN
10X	10	10:26:55	?	0.5728	4.7965	"OFF" POSITION WHEN CAME UP
A	11	10:36:50	10:41:31	0.3924	16.1153	
TRITON	12	10:49:00	10:53:05	0.052	0.0476	
9305	13	11:00:50	11:05:06	3.2548	19.1182	
24/8	14	11:09:30	11:14:20	6.9828	11.6175	
10X	15	11:26:55	11:31:32	0.6003	0.5956	
A	16	11:37:30	11:43:55	0.4017	15.4463	
TRITON	17	11:52:00	11:55:53	0.0507	0.0475	
9305	18	12:04:00	12:08:34	3.5287	18.7449	
24/8	19	12:11:00	12:15:04	7.2658	11.4411	
10X	20	12:26:55	12:31:05	0.7276	0.657	
A	21	12:35:30	?	0.4079	15.7333	"OFF" POSITION WHEN CAME UP
TRITON	22	12:47:00	12:51:46	0.0508	0.0512	
9305	23	12:59:30	13:04:41 ?	3.9597	18.556	1/2 "OFF"POSITION WHEN CAME UP
24/8	24	13:10:30	13:15:03	7.5913	11.4033	
10X	25	13:27:55	13:31:43	0.5921	0.5705	

CTD CASTS OAK I. 7/24/95

WELL LOCATION	CAST NUMBER	ATLANTIC TIME SWITCH ON	ATLANTIC TIME SWITCH OFF	SALINITY AT ONE METER	SALINITY AT BOTTOM OF CAST	REMARKS		
10X	55	19:12:50	19:17:31	0.6311	0.5701			
A	56	19:20:12	19:25:05	0.4228	3.0885			
TRITON	57	19:30:50	19:34:15	0.0532	0.0476			
9305	58	19:41:05	19:46:30	5.1155	18.0666			
NO CAST	59							
24/8	60	19:48:22	19:53:12	8.0671	11.2301			

WELL "A" IS ALSO KNOWN AS "PUMPING SHAFT"

CTD WELL LOG OAK ISLAND, N.S. JULY 25,1995

USING A 20 SECOND DELAY BEFORE LOWERING

		ATLANTIC TIME		SALINITY	SALINITY AT BOTTOM	
LOCATION	CAST NUMBER	SWITCH ON	SWITCH OFF	AT ONE METER	OF CAST	REMARKS
10X	0	9:13:00	9:17:31	0.6028	0.5687	
9302	1	9:22:00	9:26:46	1.4513	15.642	
9303	2	9:30:00	9:34:52	2.8153	15.7205	WATER SMELLED LIKE SEWAGE
10X	3	10:35:20	10:44:52	0.5709	25.5717	BOTTOM OF CAVITY

CTD WELL LOG OAK ISLAND, N.S. JULY 27, 1995

LOCATION	CAST NUMBER	ATLANTIC TIME SWITCH ON	ATLANTIC TIME SWITCH OFF	SALINITY AT ONE METER	SALINITY AT BOTTOM OF CAST	REMARKS
A	0	12:50:09	12:52	NO RECORD		CAST DID NOT LEAVE GROUND LEVEL
A	1	12:54:05	12:59:49	0.4301	23.1729	HIGHER LEVEL DUE TO PUMPING
TRITON	2	13:04:50	13:09:15	0.0567	0.0476	
9305	3	13:15:00	?	4.9676	19.533	CAME UP IN "OFF" POSITION

WELL "A" IS ALSO KNOWN AS "PUMPING SHAFT"

WATER SAMPLES TAKEN ON OAK ISLAND, N.S. JULY 26th TO JULY 27th, 1995 CTD AND FLUOROMETER READINGS DONE AUGUST 7th, 1995								
				****CTD READINGS****		****FLUOROMETER READINGS****		
DATE RETRIEVED	TIME RECOVERED	LOCATION	SAMPLE NUMBER	TIME TESTED	SALINITY	TIME TESTED	SCALE	READING
26-Jul	8:00	10X	2601	10:10	4.44	11:26	0-100	pegged
26-Jul	10:45	10X	2602	9:59	9.708	11:27	0-100	pegged
26-Jul	12:15	10X	2603	10:07	12.35	11:26	0-100	pegged
26-Jul	14:15	10X	2604	10:04	15.76	11:26	0-100	pegged
26-Jul	16:55	10X	2605	10:14	19.01	11:30	0-100	pegged
27-Jul	8:45	10X	2701	9:35	19.114	11:29	0-100	pegged
27-Jul	11:16	9303	2702	9:31	2.86	11:33	0-100	0.1
							0-31.6	0.4
							0-10	1.35
							0-3.16	
27-Jul	11:36	TRITON	2703	9:17	0.062	11:36	0-100	0.05
							0-31.6	0.2
							0-10	0.81
							0-3.16	2.4
27-Jul	11:48	A1	2704	8:54	0.144	11:39	0-100	0.2
							0-31.6	0.11
							0-10	0.5
							0-3.16	1.9
27-Jul	12:12	B1	2705	9:23	0.099	11:30	0-100	0.22
							0-31.6	
							0-10	1.1
							0-3.16	
27-Jul	12:53	9305	2706	9:45	4.893	11:46	0-100	0.02
							0-31.6	0.17

				****CTD READINGS****		****FLUOROMETER READINGS****		
DATE RECOVERED	TIME RECOVERED	LOCATION	SAMPLE NUMBER	TIME TESTED	SALINITY	TIME TESTED	SCALE	READING
							0-10	0.69
							0-3.16	2.1
27-Jul	12:58	24/8	2707	9:41	7.921	11:48	0-100	0.03
							0-31.6	0.1
							0-10	0.49
							0-3.16	1.5
27-Jul	13:28	24/8	2708	9:54	8.72	11:43	0-100	0.05
							0-31.6	0.12
							0-10	0.55
							0-3.16	1.82
27-Jul	13:31	9301	2709	9:48	13.324	11:41	0-100	0.02
							0-31.6	0.15
							0-10	0.62
							0-3.16	1.9

Table 3
PTL locations

PTL #	Location	Deployed
1	9303	1600: 25/7/95
3	10x	1200, 24/7/95
4	Triton	1445, 25/7/95
6	Pier	0925, 24/7/95

We deployed PTL's in four locations. PTL's are pressure-temperature loggers, designed and constructed by Wayne Spencer at WHOI. The PTL's have an accuracy of approximately 1 cm, and record internally for up to several months. The PTL's have an accurate time base, and provide a simple, automated way to monitor the behavior of water levels in the wells, both with and without pumping.

In theory, comparison of the PTL data from the open ocean and from each well will provide information on the degree of hydraulic connectivity. It will not be a direct indication of how much salt water exchanges on a tide, but it does permit some crude calculations about size of the tunnel permitting the exchange, for instance. In order to make these calculations, one must measure the time lag between the tide in the open ocean and the borehole, as well as the decay in amplitude in the tide. Calculations demonstrating this capability have been presented to Oak Island Discoveries in the past.

CTD observations in nearshore waters

The CTD was also used in a second mode: towed behind the vessel Blue Eagle, during times when the dye tests were run. These CTD tows permitting continuous monitoring of the salinity and temperature of the water column in the nearshore zone, allowing definition of anomalous zones of water, where, for instance, groundwater might be percolating into the sea water. Data were recorded internally in the CTD, and processed later using the SeaBird software.

Dye tests and borehole pumping

In order to evaluate the lateral connectivity of the various boreholes, as well as their connection with the shoreline and offshore waters, we conducted dye tests. The dye used during these tests was rhodamine B, a dye used extensively in groundwater and sea water tests. This dye is useful because it does not decay rapidly with time, and is easily detected in groundwater and surface waters using a Turner fluorometer. The Turner fluorometer was aboard the vessel, fed by pumped water from plastic tubing towed behind the vessel Blue Eagle, next to the CTD, to detect penetration of the dye into the marine waters through groundwater connections. The fluorometer would detect the dye, whereas the CTD would give the salinity, temperature and depth of the detected signal.

Previous attempts to use dye as a tracer have produced highly inconsistent results. Dye tests in the early 1990's reported positive results, where dye inserted into 10-x was reported to be found off the south shore and off Smiths Cove. However, other attempts by Golder Associates in 1969 and 1970 showed no leakage of dye to the shoreline. Since part of the difficulty associated with dye tests in the past may have been due to poor resolution of dye presence, we used the Turner fluorometer which has a detection limit of one part per billion (ppb) for the rhodamine B dye.

Dye tests were conducted in Hole 10-x, by introducing large amounts of dye (nearly three pounds over two days), into 10-x, then pumping into 10-x to maintain an eight-foot head of water in the hole to provide a hydrostatic head to drive groundwater flow from the borehole to the shoreline. Using this technique, with the instruments available, we could detect the dye even if it were diluted by near 500 million gallons of water.

The water source for our test was salt water taken from the coast along south shore. The water was pumped to 10-x using a large-capacity pump which operated at several hundred gallons a minute. During the two days of pumping we pumped approximately 400,000 gallons of salt water into hole 10-x. This is equivalent to filling a cavern some 25'X25'X80' with water. If the dye were evenly distributed with this water, the resulting concentration would be one part per million (1 ppm), 1000 times the detection limit. If this 400,000 gallons of dye were then diluted a further 1000 times, to get to the detection limit, it would require nearly 400,000,000 gallons of water!

Because 10x is cased all the way to the upper bedrock surface, and has concrete around the casing to prevent intrusion of water from the casing exterior, we pumped the water and dye directly into the bedrock cavity below 10-x. This location will not provide information on flood tunnels within the overburden tills, but rather will only indicate the degree of hydraulic connectivity within the bedrock cavities. Unfortunately, there was too little time to arrange for pvc-cased and screened wells made specially for these dye tests; we were limited to use of 10-x, where recent exploration has focused.

The fluorometer was calibrated on 27 July 1995 and again on 7 August 1995. The calibration was linear throughout the measured range from 10 ppb to 1000 ppb. Detectibility was excellent and repeatability of readings was excellent between the two calibrations (within much less than 10% in general). Standards from Turner were used for the calibration.

Beach pits and morphological observations

Eight sites were selected along the shoreline of the eastern portion of Oak Island, Nova Scotia to serve as locations for subsurface sampling. Beach pits provided a stratigraphic picture of the island's shoreline and helped to determine the shoreline history. Examination of the sediments beneath the shore face also indicated the processes affecting the shoreline over time. In particular, we sought to find preserved organic matter which could then be dated using carbon-14 dating techniques to present quantitative estimates of nearshore sedimentation rates as well as rates of relative sea-level change.

Eight sites were chosen along the eastern half of Oak Island from the beach bordering the central marsh (south shore) to the shoreline immediately north of the former coffer dam in Smith's Cove. In most cases, investigators attempted to chose locations which were most likely to have been undisturbed by previous Oak Island investigators. The exceptions were beach pit numbers one and six. Since the initial field work was completed it is believed that the work of Bob Dunfield may have altered the area near beach pit number 1. Beach pit number 6, possibly in a disturbed area, may have been affected by the extensive work and digging around the coffer dam. The remainder of the digging locations lie in areas that appeared to be undisturbed. Dan Henskee provided counsel in the choosing of these excavation sites.

The pits were excavated with a backhoe under the direction of one of the investigators. Holes were initially dug to three-to-four feet and then examined, sampled and logged. The pits were then dug deeper to eight or ten feet. At this level holes were again sampled and logged. After depths of six feet, first-hand examinations inside the holes became too risky because of the possibility of the failure of the pit walls which were weakened by groundwater infiltration. In most cases digging ceased at this level because there was little indication of bedding changes below. Upon the completion of the final sampling and logging, the holes were filled in and their locations were marked with stakes. Later their positions were surveyed and recorded with a portable differential GPS system.

Organic material from the beach pits was prepared for dating at the AMS facility in Woods Hole, Massachusetts. Two small jars of peat were sent to the facility for dating along with two wood samples and three samples of possible coconut fiber. Before the samples could be analyzed they had to be dried in an oven. The peat samples had to be thoroughly homogenized, ensuring all the material from each sample would provide a mix of similar material for the analysis. The separately homogenized samples were then subsampled three times for analytical purposes for a more accurate date.

Results

Bathymetry and side-scan sonar

A high-resolution bathymetric map was created from the field data collected over a five-day period. A large quantity of depth data are available in the area close to the south shore and Smith's Cove. The bathymetry map shows a steep shore face to a depth of 10 meters along most of Oak Island. An exception is close to the causeway: The water depth levels off at about 4 meters in the area close to the causeway, rather than leveling off at the 10 meter depth around most of Oak Island.

Side-scan sonar shows many large boulders surrounding Oak Island. This observation is backed up by diver observation of large boulders in the area. Divers also found extensive beds of living eel grass in both Smith's Cove and south shore. No obvious manmade offshore structures were observed in the side-scan record or by divers in Smith's Cove or at South Shore. A few old timbers were found by WHOI divers but these were free debris on the bottom, not indicating any man-made structure.

In past years, reports of "ice holes" and dye diffusing from nearshore locations along the south shore have emerged. Blankenship and colleagues have explored these locations using scuba observations. In at least one instance they found bubbles smelling of methane emerging from the sediments. Twice during the past decade, divers probed for a "water tunnel" at these depths, to no avail. However, we could find no evidence of possible tunnels from our side-scan sonar records. Though we saw numerous shallow depressions characteristic of a boulder-strewn, eroded nearshore zone, we could identify no structures or organized features which could explain the "ice holes" or other observations by Blankenship.

Methane (or perhaps hydrogen sulfide?) degassing can be explained by decomposition of organic debris. Abundant eel grass was observed in the area, along with numerous other types of algae. Because of the dead spaces between the boulders, decaying vegetative matter will remain in place and not necessarily be swept away by storm waves and currents. Decomposition of this vegetation concomitant with low levels of sedimentation will generate methane or hydrogen sulfide, depending on the oxygen conditions in the decaying mat. Out-gassing of these sediments would be expected to be not uncommon.

CTD observation in boreholes

The top elevation of the boreholes were surveyed in first to provide a common datum. GPS was not available for on-island vertical control because we left the GPS on site for only short periods of time. Instead, we used a self-leveling level and rod to obtain relative elevations. Table 1 presents the relative elevations of the surveyed wells in relation to borehole 10x. CTD casts were taken in boreholes 10x, A (pumping shaft, to the NE of 10x), Triton, 9305, and 24/8 (Fig. 2). Table 2 provides a listing of all CTD casts by cast number and by time. It also summarizes salinity at one meter from the surface of the water, and the salinity at the bottom of the cast. These cast numbers and the date must be used to interpret the CTD data from Attachment A. For instance, CTD cast MAHO2459 refers to Mahone Bay CTD cast on 24 July, 1995, cast number 59. MAHO2802 refers to cast 2 from 28 July 1995.

Pressure is shown in units of decibars (db). 1 decibar is approximately equal to 1 meter, so the decibar scale can be read as meters. Depths are referenced to the water surface at that well, not to an absolute datum. We did not survey in all water elevations, to determine the absolute water level between all wells on the Island.

10x: Salinity at 10x is near zero for the entire water column, except near the bottom at approximately 39 m (128') to 55 m (180') where the salinity increased to nearly 25 ppt. Ocean water in Mahone Bay, by contrast, is approximately 30 ppt. Temperature in the shaft was approximately 8°C throughout the water column.

Both salinity and temperature were constant over the two-day measurement interval (see Attachment B for data sheets).

Borehole A (pumping shaft): Temperature here was approximately 8°C throughout the water column for the entire duration of measurement. Salinity is low, until a depth of 35 m (115') to the maximum depth measured (40 m or 131'). Salinity reached a maximum of approximately 20 ppt.

Fig. 2 here

Triton shaft: Triton shaft had a temperature of about 7°C, for the entire period. No measurable salinity was present.

Borehole 9302: Measured only once (on 25/7/95), the salinity was low (1.5 ppt) from the surface to 32 m depth (105'), where it increased to about 15 ppt at a depth of 40 m (131').

Borehole 9303: Measured only once (on 25/7/95), the salinity was low at the surface (2.5 ppt), increasing to 15 ppt at a depth of 40 m (131').

Borehole 9305: Temperature was a uniform 8°C for the entire water column and the entire period of measurement. Salinity profile was more complex, with a salinity of about 3 ppt at the surface, declining uniformly to 14 ppt at 10 m depth, where it was constant until a depth of 32 m, at which point it increased gradually to 19 ppt at a depth of 42 m (138'). This profile varied within only about 1 ppt for the two-day measurement interval. This variation was due to mixing near the first inflection point at 10m, perhaps due to insertion and withdrawal of the CTD (which took up much of the well diameter).

Borehole 24/8: Temperature was constant at between 7 and 7.5°C throughout the entire period of measurement. Salinity was higher than in borehole 9305: approximately 7.5 ppt at the surface, increasing gradually to 5 m depth to 10 ppt, constant from 5 m to 30 m (98') depth, increasing gradually from there to 12.5 ppt at 43 m (141') depth.

The CTD measurements in the boreholes clearly show a marine water influence at a depth of 100 feet and greater, on average. The wells around 24/8 have higher salinities than those farther away (Triton, pumping shaft, and 10-x) at the higher elevations; all have salinity of 20-25 pt near the bottom of their sampled depths (except Triton which was too shallow). This marine influence could come from a deep-water connection near the base of the well (in the anhydrite/gypsum cavities, for instance), or perhaps some is remnant from earlier pumping of saltwater into the well casings. Because the wells near 24/8 have been capped, direct precipitation into the wells has not occurred, so any remnant salt water in the wells is going to stay a long time. By contrast, Triton and 10-x are relatively open to recharge, so the salt water introduced by previous salt water pumping would have come into equilibrium with new freshwater input in the intervening five years since pumping occurred.

Tide gauge/piezometer observations

Four tide gauges were installed at the site (Table 3): one at the pier at Chester Harbor (ocean tide gauge), one at 9303, one at 10x, and the final one at Triton Shaft. Each gauge operated for approximately one month's time. The gauges measured water pressure (converted to water surface elevation) and water temperature.

The tide-gauge records, converted to surface elevation, are plotted on Fig. 3. The Mahone Bay tide is strong: approximately 2 m (6.1 ft.) in height. The tide in 10x was also relatively strong, with a daily height of about 50 cm (1.64 ft). Tides in well 9303 were noticeable, but not large: perhaps 5 cm in height (about 2 inches). There was no visible tide in the Triton Shaft.

In order to compare the tidal information, we used harmonic analysis, a simple mathematical technique that is designed to determine how much of the tide belongs to various constituents. Remembering that the tide has nearly 300 constituents in total, we chose to identify only the two major tides: the 24-hour K1 (solar diurnal tide) and 12.4-hr M2 (lunar semi-diurnal). Though other constituents can be calculated from the available data, for the purposes of our exploration we focused only on the principal twice-a-day (semi-diurnal) and daily (diurnal) tides. Calculations for these two constituents confirm the visual impressions one gets from review of Fig. 3 (Table 4). The Mahone Bay tidal amplitude is largest, with a height of about 1.5 m for the semi-diurnal tide, and 0.15 m for the diurnal tide. Borehole 10x has the next largest tide (0.65 m for the semi-diurnal, and 0.08 for the diurnal). Triton Shaft has no tide (since it has no access to bedrock), whereas Borehole 9303 has a semi-diurnal height of 0.08m and a diurnal height of 0.04 m.

Table 4

Diurnal and Semi-diurnal Tidal Heights and Phases

Location	Diurnal tidal height (Phase in hours)	Semi-diurnal height (Phase in hours)
Mahone Bay	0.15 m (17 hours)	1.49 m (1.4 hours)
Borehole 10x	0.08 m (18.8 hours)	0.65 m (2.27)
Triton Shaft	0.007 m (not applicable)	0.014 m (not applicable)
Borehole 9303	0.04 m (22.93 hours)	0.08 m (5.52 hours)

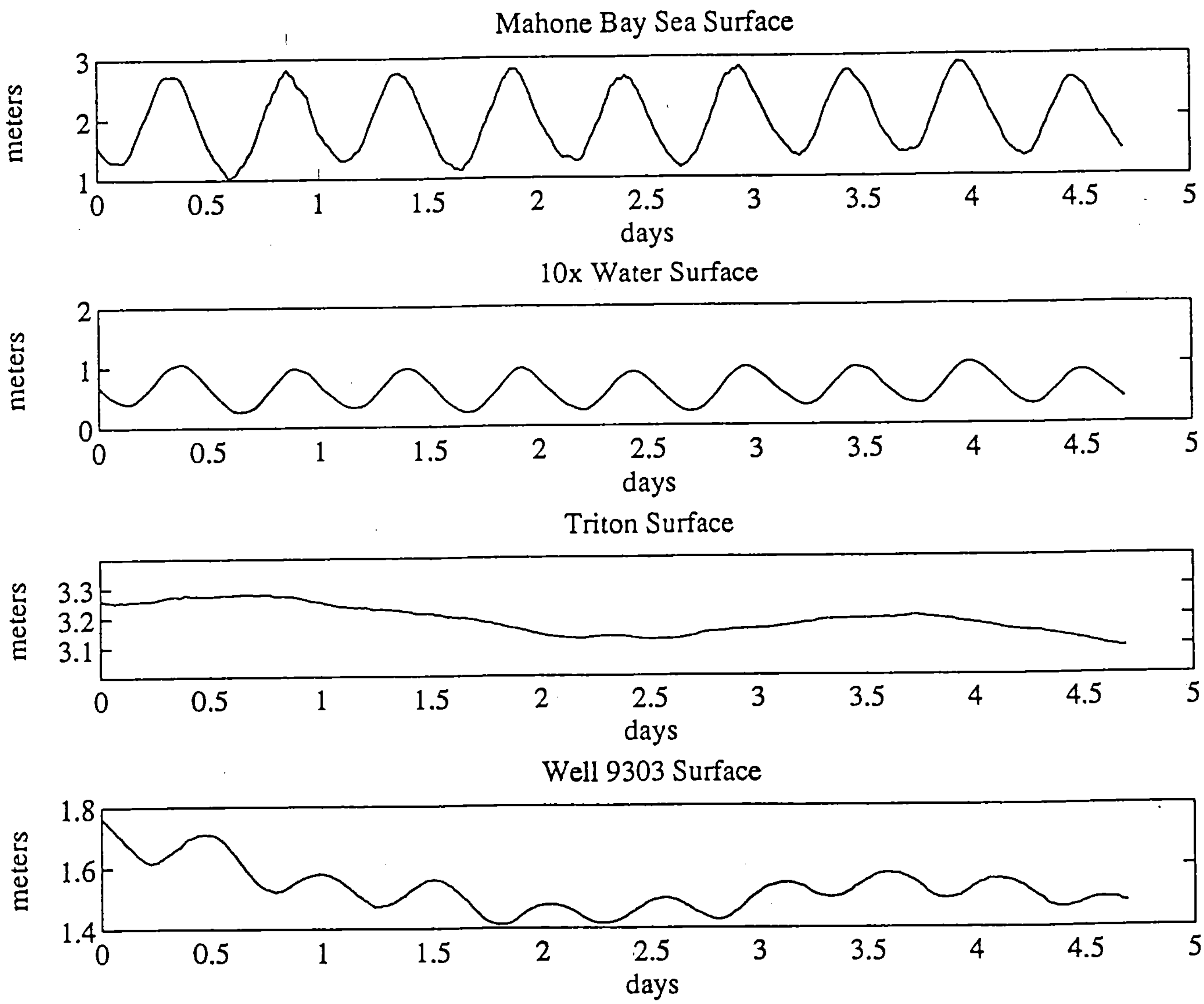

Mahone Bay Sea Surface
meters
3
2
1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days
10x Water Surface
meters
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days
Triton Surface
meters
3.3
3.2
3.1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days
Well 9303 Surface
meters
1.8
1.6
1.4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days

Figure 3

Equally important information about tidal behavior can be determined from the phase of the tide. The phase of the tide refers to what time high tide (or low tide) reaches a particular location. Even if the tidal height is the same along a coast, the tide will take time to propagate from one location to the next. The time difference between high or low tide at two separate locations is a function of two primary factors: the distance between the stations, and the hydraulic characteristics of the water body joining them. Hydraulic characteristics include water depth, friction in the channel, etc. Tides propagate in open water rapidly, but they propagate in groundwater only slowly. Tides propagate more slowly in fine sediments such as clay or silt, and more rapidly in either open channels (flood tunnels) or sandy materials.

The semi-diurnal data for Oak Island show a time lag of some 52 minutes between Mahone Bay high water and the high water in Borehole 10x. It then takes some 3 hr 15 min. for the tide to propagate from 10x to 9303. These values are approximately doubled for the diurnal tide.

What can one conclude from the tidal data?

First, the strong decay in tidal amplitude between Mahone Bay and Borehole 10x demonstrates that the tidal connection between the two sites is poor: there is no large open tidal channel that permits rapid and complete connection between the open bay and 10x. However, the decay shows either that the tidal communication is limited to a small shaft, tunnel, or cavern, or that the tidal communication is through sediments (coarser such as sand). The phase information shows that the tide between Mahone Bay and Borehole 10x is retarded nearly an hour. This lag again suggests tidal flow through either a narrow channel, or through sediments. We cannot distinguish between these two possibilities using available data. The CTD data show tidal fluctuations at the freshwater/saltwater interface in borehole 10x, but provides no additional information.

The tidal connection between Borehole 10x and Borehole 9303 is poor. Little of the tidal amplitude propagates to borehole 9303 from 10x (or the shore). In addition, the time lag is more than three hours, suggesting there is no open cavern between 10x and 9303. Instead, the tide must propagate through either a very narrow tunnel or cavern connecting the two, or, more likely, through a wide sediment layer which restricts free communication. Since both 10x and 9303 are grounded in the bedrock, it appears that there is no open cavern beneath the Money Pit area and hole 10x: rather, the two areas are connected by sediment in caverns (at best) or by fractures in the bedrock. Geological information from previous searchers suggests there are small caverns or cavities, which are at least partially filled with sediments.

When we subtract from the original tidal signal (Fig. 3) the harmonic tide, we obtain the tidal "residual" signal (Fig. 4). This tidal residual shows the non-tidal part of the water level change. The important features here are that borehole 9303 and 10x, and the Triton Shaft, show a small residual with a low near day 2.5, and a high near days 0.5 and 3.5. This fluctuation may reflect recharge from the groundwater table, or a slowly-varying ocean level (less likely based on the Mahone Bay residual).

CTD observations in nearshore waters

Following the CTD measurements in the wells, and during the dye tests, the CTD was towed behind the vessel Blue Eagle. These tows were made to determine if we could identify sites where freshwater from Oak Island was discharging into Mahone Bay. Such sites would be identified from fresher water and cooler temperatures than the bay waters. Because the groundwater would be mixed rapidly with Bay water, we may many transects to see if we could identify any single points or measurements where we might be able to identify groundwater inflow. All measurements were made while the differential GPS was operating, so we could identify the exact spot of the discharge to Mahone Bay.

On 26 July, 1995, the CTD was towed all around Oak Island. The results of this tow are shown in Fig. 5. The tow shows uniform temperature around the island of about 18°C, and uniform salinity of about 28 ppt. The few deviations from these average values were examined, and represent transients when the instrument was raised or lowered, rather than being an actual difference in the water characteristics. The day-long tow therefore could not identify any significant freshwater discharges. This should not be a major discovery, since the island is small, and the discharge to the ocean must be small. If the discharge to the ocean were large, the water level on the island would be the same as in the ocean (or very nearly so). That the water levels are elevated on the island compared to the ocean shows the hydraulic connection between the ocean and the island is weak.

Attachment C shows individual CTD casts made around Oak Island on 28 July 1995, made to search for water-column changes (salt and temperature). These casts all show uniformly similar data: temperature is nearly 22°C near the surface, decreasing near the bottom to about 10°C in some stations. Salinity is always nearly

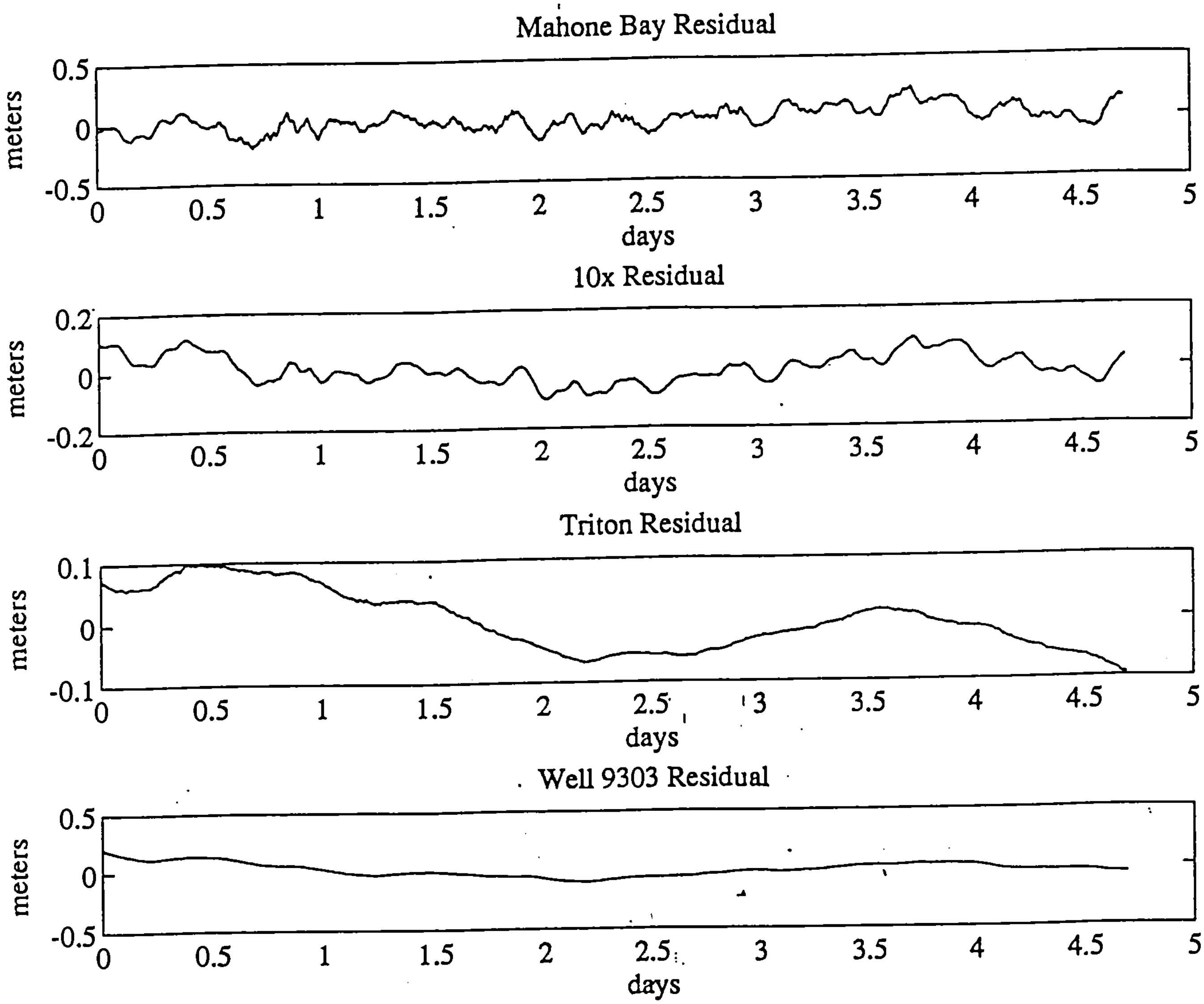
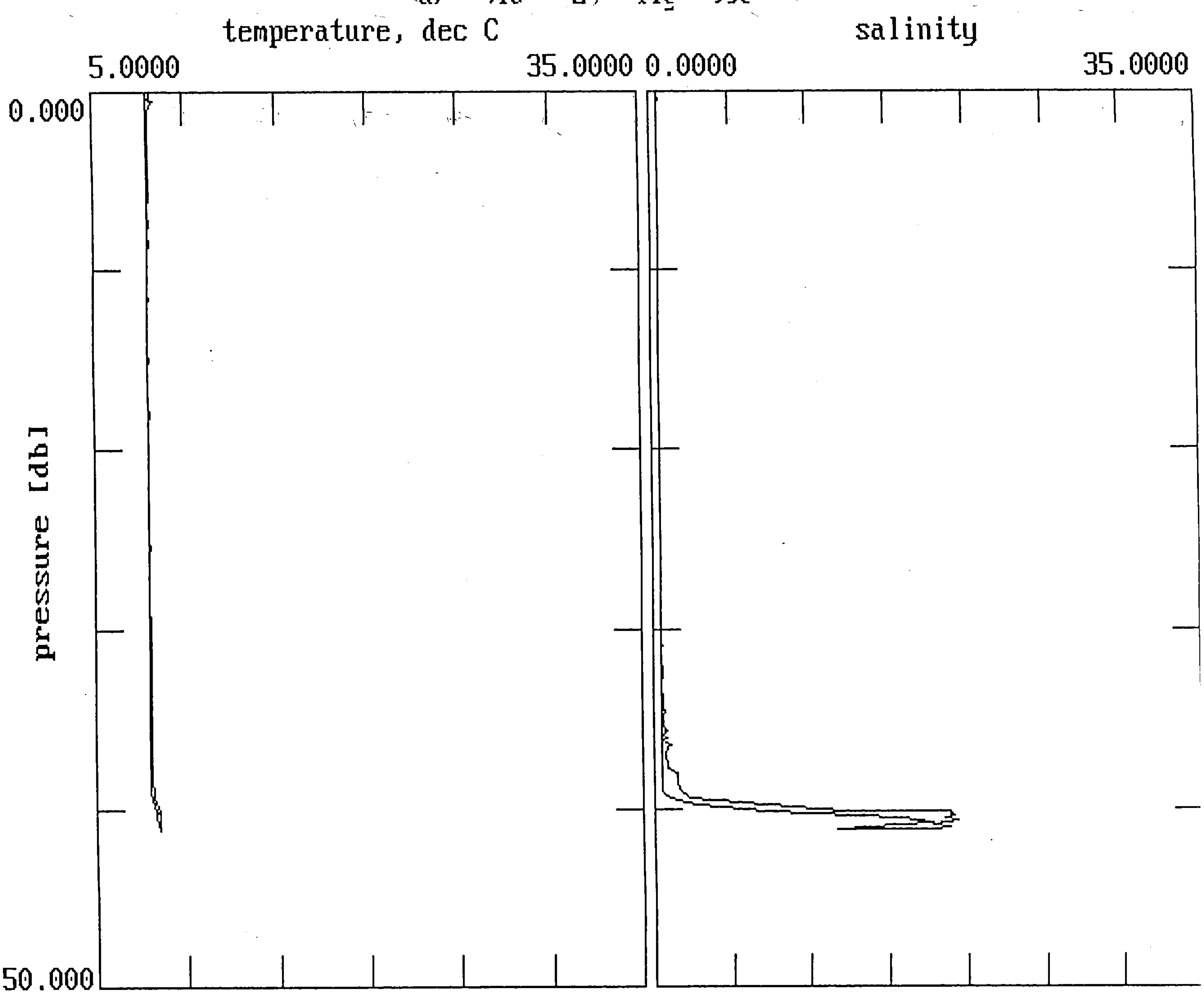
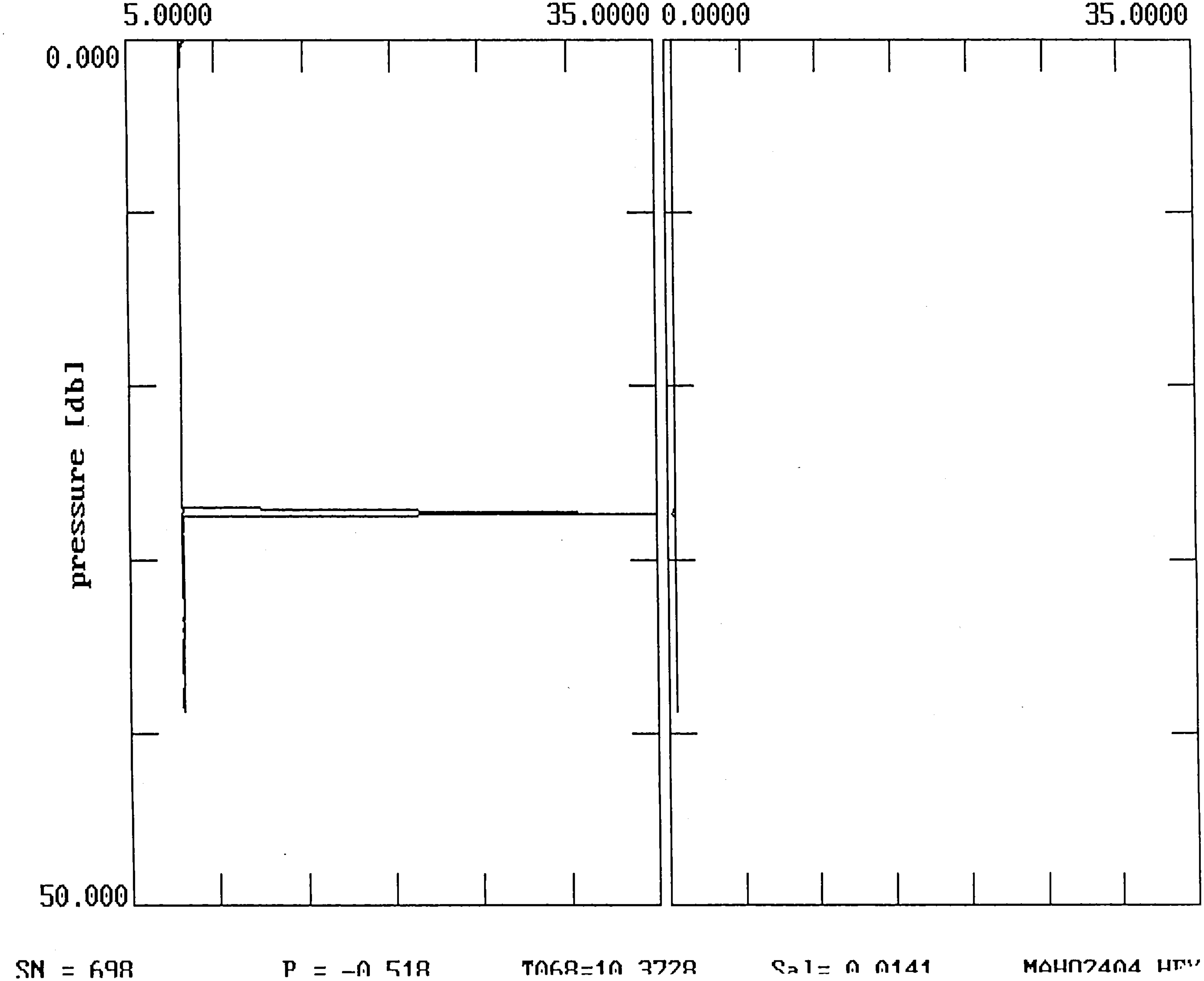

Mahone Bay Residual
0.5
0
-0.5
meters
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days
10x Residual
0.2
0
-0.2
meters
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days
Triton Residual
0.1
0
-0.1
meters
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days
Well 9303 Residual
0.5
0
-0.5
meters
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
days

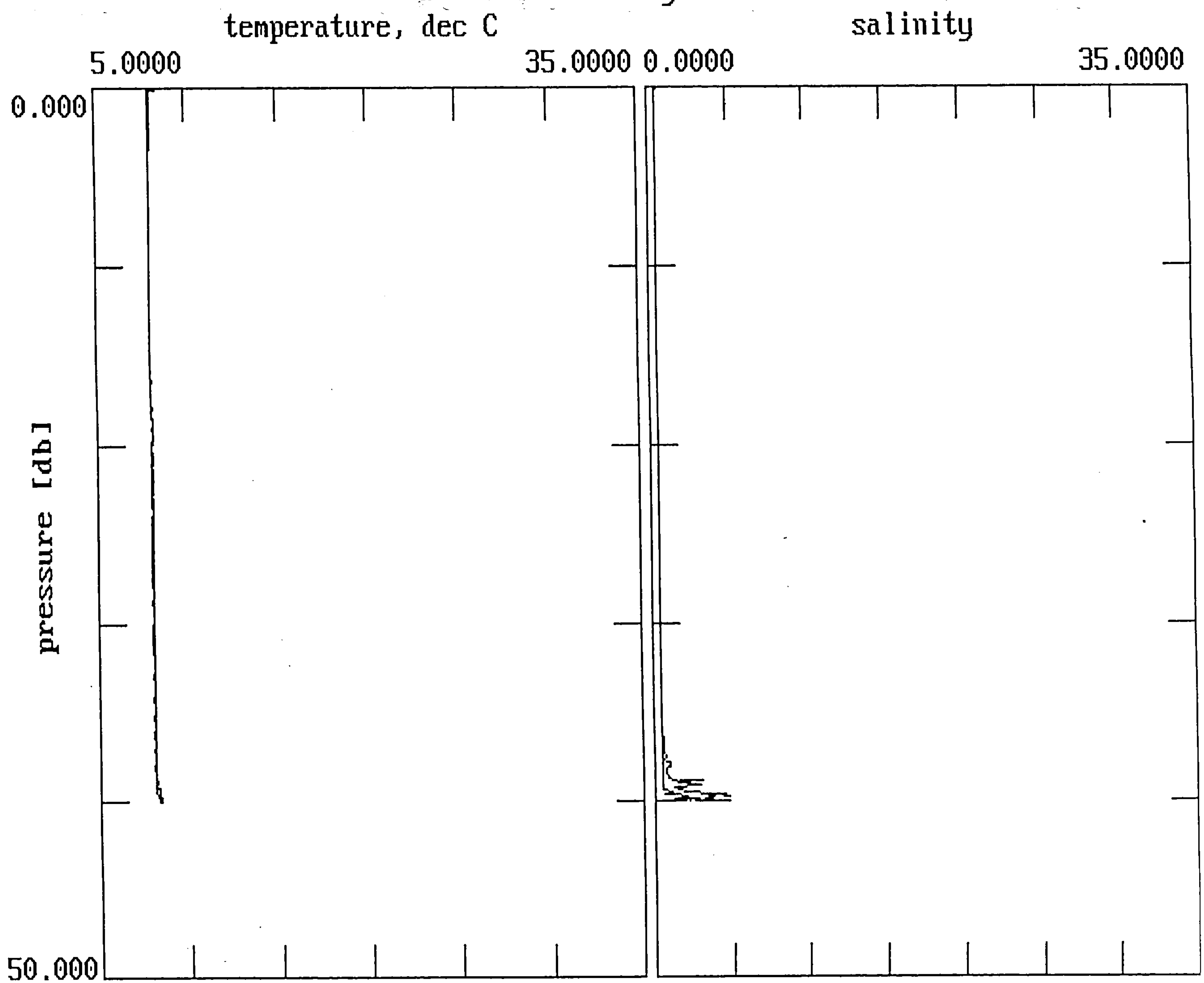
Figure 4



SN = 490 P = -0.196 T068=10.5728 Sal= 0.0171 MAHO2400.HEX



temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
50.000
pressure [db]
SN = 698
P = -0.518
T068=10.3728
Sal= 0.0141
MAH02404.HEX



SN = 476 P = -0.706 T068=9.1406 Sal= 0.0166 MAHO2410.HEX

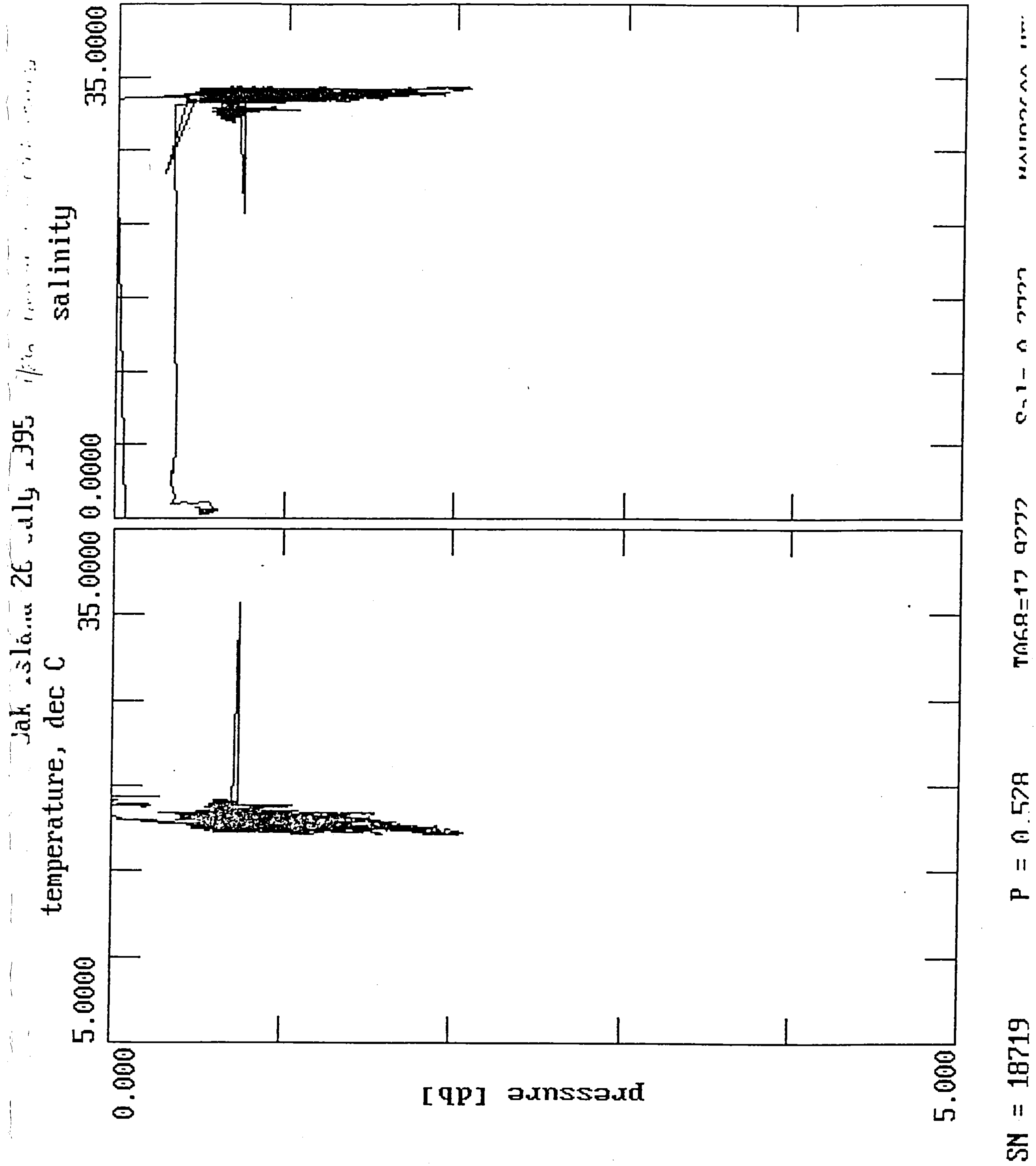

salinity
temperature, dec C
pressure [db]
35.0000
0.0000
35.0000
5.0000
0.000
5.000
SN = 18719
P = 0.528

Figure 5

constant in a single cast, ranging from about 27.5 ppt to 30 ppt in a few locations. Some microstructure is seen in some casts: uniform temperature and salinity in near surface waters (perhaps 10-15 cm thick), followed by a gradual increase in salinity and decrease in temperature below this thin thermocline. There was no evidence of significant freshwater inflow provided by the CTD casts.

Dye tests and borehole pumping

Dye tests were conducted from 26 to 27 July 1995, at which time the fluorometer aboard the Blue Eagle was used offshore to try to detect dye in offshore waters. Fluorometer measurements continued until 28 July 1995, in an attempt to trace the dye from borehole 10x.

Prior to introduction of dye into borehole 10x, the Blue Eagle did a fluorometer survey around Oak Island. Higher fluorometer readings (to 3-5 ppb) were found along both sides of the causeway from the mainland to Oak Island, during high tide. We hypothesize that this dye was from dye tests some year or more ago, which remained in low quantities, but sufficient to measure with our accurate equipment. The next day, during ebbing tide, we measured some dye (a few ppb) in the area near Smith's Cove. At first thinking this might be from our dye tests in 10-x, we subsequently traced this dye back to the causeway, showing that this dye was only the same dye we had measured the day before, only advected with the ebbing tide.

Dye was first introduced in the morning of 26 July 1995. From the time the dye was first introduced and for a period of four days, continuous fluorometer tracks were run along the south shore and along Smith's Cove, in an attempt to measure dye discharging from 10-x. We were unable to find any trace of dye in Mahone Bay during the four days of observation. Tracklines were run not only along the shore, but also cross-shore, and out to distances of 1 km from the shore (though most measurements were concentrated within 100 m of shore).

Any saltwater entering the cavern at the base of 10-x would immediately become dyed due to mixing with the dyed water in 10-x. Any water leaving 10-x to the ocean would be dyed due to mixing, and the tidal water discharged through any hydraulic connection would be dyed enough to be detected. This lack of observation of dyed water discharging to Mahone Bay indicates the following:

There is no direct connection of seawater between the base of borehole 10-x and the ocean.

Whatever tidal connection exists between 10-x and the ocean, the connection is indirect and probably through sediments, so tidal exchange is with interstitial water in the sediments, not with water from the cavern itself.

During the dye tests and accompanying the pumping, water rushed from the wells surrounding the money pit.

Water samples were taken at the boreholes from time-to-time to quantify the concentration of dye in the samples. Water samples (Table 5) from 10-x were consistently higher than 1 ppm, since the fluorometer was pegged (off scale). Water samples taken on day 2 of the dye tests (more than 24 hours after the dye was introduced first), showed some detectable dye at boreholes 9303 and Hedden Shaft. After excessive pumping on day 2, the area around the Hedden Shaft was flooding due to large heads on borehole 10x. A visible pink color (color of dye) in the water emanating from the boreholes was present. Measured concentrations of dye were up to 50 ppb, after which water sampling was stopped. Salinity in the wells increased gradually as pumping continued, indicating mixing of the fresh water with upward welling and dyed water coming from the base of the wells. These measurement showed:

There is some hydraulic connection between borehole 10x and the boreholes near the Money Pit, even through the bedrock where all boreholes are grounded.

There is poor connection between borehole 10-x and the Triton Shaft, though some measurable was present in Triton Shaft within one day of the introduction of dye into borehole 10-x. This dye was at a low detection limit; its source is unknown since we know Triton Shaft does not go to bedrock, and we introduced dye into the bedrock. There may be some other, poor connectivity between the boreholes at a higher level. Salinity in the Triton Shaft, at the time of measurement of the dye concentration, was 0.06 ppt, barely measurable, but consistent with low levels of dye.

Beach pits and morphological observations

The majority of the beach pits with the exception of numbers ~~one and~~ two and eight yielded similar shoreline stratigraphy (see Fig. 2). These deposits reflect glacial deposition which has been reworked by shoreline processes. The sediments on the island's shoreline are mainly granitic in origin (consistent with erosion of the Devon-Carboniferous granite intrusion at the north end of Mahone Bay, the source area for the surface sediments on Oak Island). There are also a large portion of slate fragments in the sediments along the shoreline which are linked to the adjacent Halifax Formation which may underlie the western half of the island. This formation is composed of a Mississippian slate (300 to 345 mya). Except for beach pits two and eight, the island sediments are composed mainly of lodgement till associated with drumlin deposition.

Table 5
Borehole Water Samples
26-27 July 1995

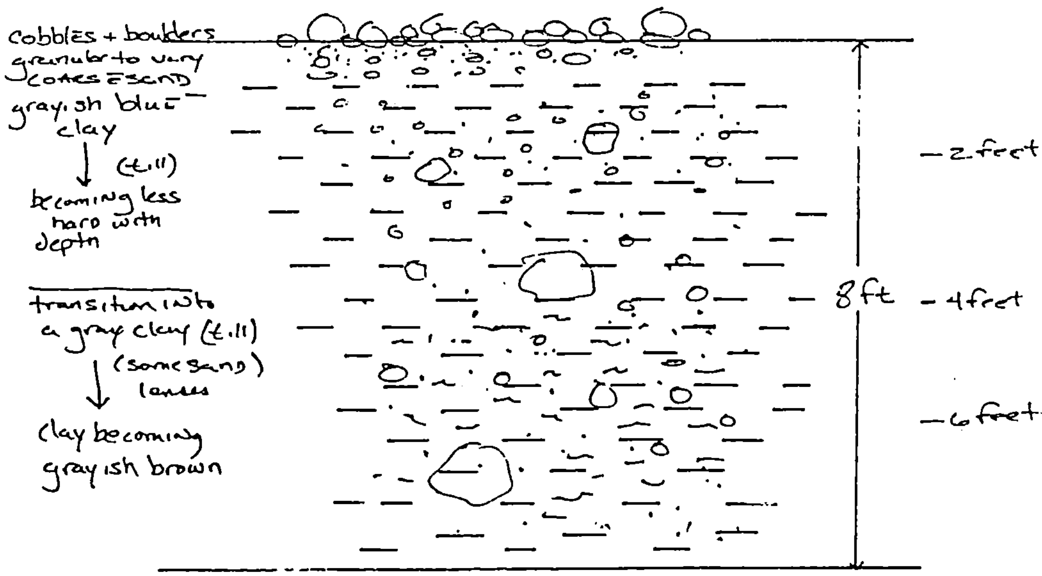
Borehole #	Date	Time (EDT)	Sample #	Salinity (ppt)	Concentration (ppb)
10x	26 July 1995	0800	2601	4.4	Off scale*
10x	26 July 1995	1045	2602	9.7	off scale
10x	26 July 1995	1215	2603	12.4	off scale
10x	26 July 1995	1415	2604	15.8	off scale
10x	26 July 1995	1655	2605	19.0	off scale
10x	27 July 1995	0845	2701	19.1	off scale
9303	27 July 1995	1116	2702	2.9	25
Triton shaft	27 July 1995	1136	2703	0.06	10
Pump shaft	27 July 1995	1148	2704	0.1	10
B1	27 July 1995	1212	2705	0.1	50
Money Pit	27 July 1995	1253	2706	4.9	10
24/8	27 July 1995	1258	2707	7.9	10
24/8	27 July 1995	1328	2708	8.7	10
Money Pit	27 July 1995	1331	2709	13.3	10

* off-scale indicates reading greater than 1000 ppb (1000 times the detection limit)

Beach Pit 1

The shoreline surrounding beach pit 1 (Fig. 6) is common of the shore lines in regions affected by glaciation. Cobbles and boulders dominated the surface at the shoreline at this site. Below this a granular-to-very-coarse sand underlays the cobble and boulder dominated surface. Sand in this layer is composed mainly of quartz grains as well as rock fragments from weathered rock transported by glacial processes. Fragments of gravel-sized flat slate are also present in the surface layers. This material fines into a hard grayish blue clay which has an abundance of coarser silt, sand and gravel. The bluish gray clay which is impervious to water is tightly compacted and contains fewer clastic sediments relative to the underlying

Beach pit 1. location: 44 30.739N
046 17.347W



Beach pit 2 location:44 30.767N
64 17.464W

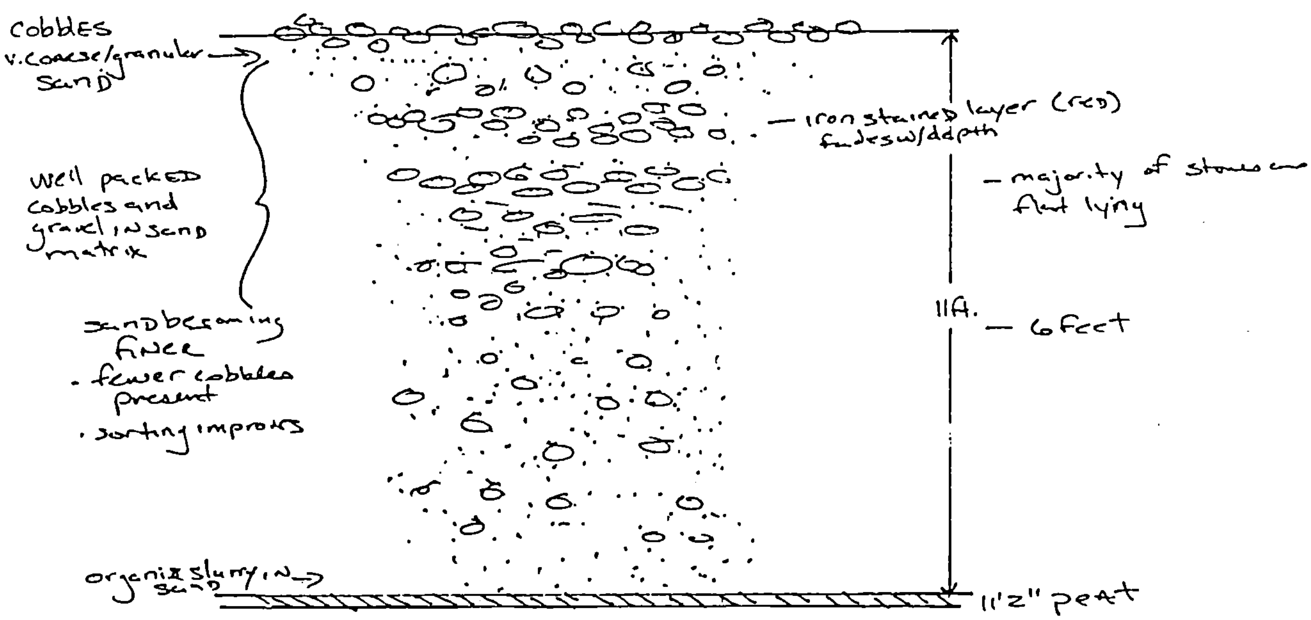


Figure 6

sediments. A few boulders are also present in this sediment layer. One wall of the pit also yielded a half inch layer of medium-to-well-sorted sand. Beneath the sand layer, the blue/gray clay continues, becoming softer and more saturated below four feet. The clay continues to a brownish gray clay as the pit approaches six-to-seven feet. This sediment is still filled with larger grain sizes ranging from boulders to more frequent cobbles and sand. Sand lenses are also interdispersed in this stratum. Sediments in this beach pit are consistent with till associated with glacial processes.

Beach Pit 2

This pit is located along a barrier beach which formed between the interior, central marsh of Oak Island and Mahone Bay. The surface sediments (Fig. 6) are composed of many cobble-sized fragments with few boulders, representative of a cobble (or shingle) beach in a sand-starved region. These cobbles are uniform in size along this portion of the beach and overlay a granular sand composed mainly of quartz and granite fragments. There is also an abundance of slate fragments in these sediments. A sand layer predominates deeper into the pit and supports sometimes well packed layers of cobbles and gravel sized fragments similar to those at the surface. Occasionally, a boulder occurred in the sequence. Groundwater flow through these sediments occurred near two feet into the pit, and was present through the rest of the digging. The water flow was rapid as it flowed from the fresh water marsh toward Mahone Bay. At three feet the sediments were stained deep red from the oxidation of iron in the groundwater. As the groundwater travels from the typically anoxic bottom waters of the marsh, it encounters oxygenated sediment which can then oxidize the reduced iron in the water causing it to precipitate on the sediments staining them red. This phenomena is evident at the surface of the western portion of this beach where ground water percolated through the surface of the beach. The iron layer persisted for nearly six inches and then faded with depth.

Approaching six feet, the sediments became finer (coarse/very coarse sand) and there were fewer coarse sediments in the sand matrix. Between six and ten feet, the sand became slightly coarser with some intervals of coarser sediments such as layers of packed cobbles. By ten feet, the sand became darker (dark grayish brown) and smelled of reduced organic material. A layer of peat was encountered at eleven feet two inches. The peat contained organics from dead plant material, in particular small tree branches were visible. This organic material was sampled for radio-carbon analysis.

Beach Pit 3

The shoreline encompassing beach pit 3 (Fig. 7) was similar to that of number one with large cobbles and boulders dominating the beach surface. Beneath the surface layer, a granular sand provided a matrix for the overlying cobbles and boulders. Six inches below the sand-boulder boundary, there was an eight inch layer of organic material. This sediment probably resulted from the burial and decomposition of shoreline vegetation. The organic layer then proceeded into a gray clay that faded to a grayish brown clay. The clay beneath the organic layer was dominated by a clay matrix but had large amounts of sand, silt, gravel, cobbles, and boulders mixed in. Additionally, small sand lenses about an inch long were dispersed in this layer. This hole was taken to a depth of nine feet.

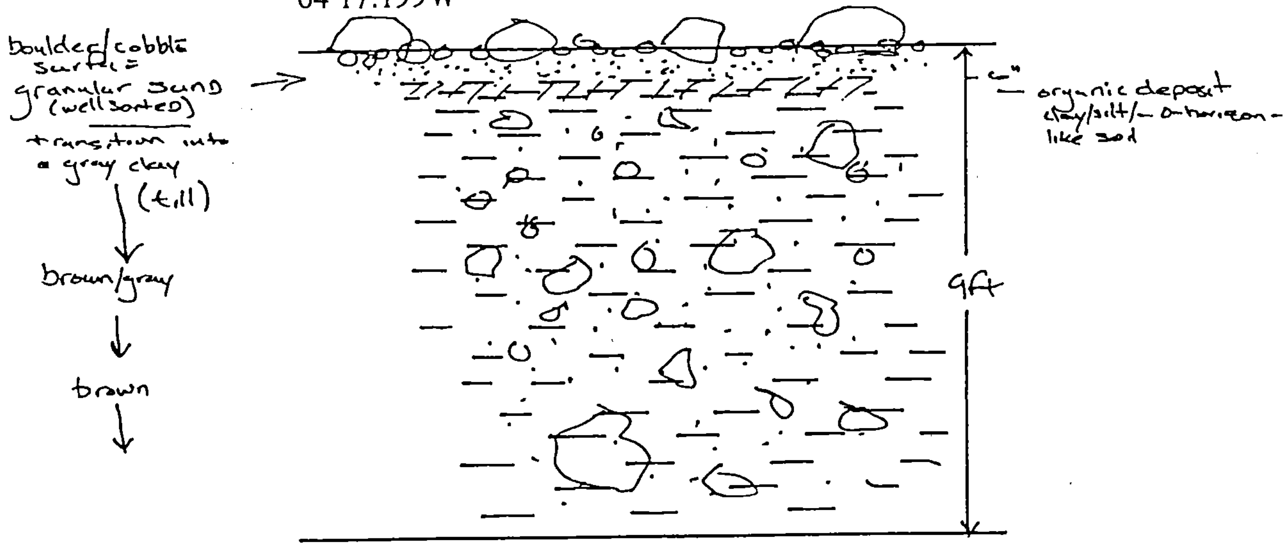
Beach Pits 4 and 5

Beach pits 4 (Fig. 7) and 5 (Fig. 8) followed a similar stratigraphic pattern to that of pit 3. The surficial layer in this area was similar to that of 1 and 3, but boulders were more common in this area. No organic layer was encountered in either of these pits. Beneath the surface the sediments were composed of a granular sand with mostly rock and quartz fragments with some flat granules of slate. By eight inches the sand had fined into the same brown clay encountered in previous excavations. In pit four, water flowed readily through the poorly sorted clay. Cobbles and boulders were also common in the clay matrix. Weathered granites and slates were common in both of these pits. The weathered granites would crumble into fragments when disturbed. Well-weathered slates were present as soft, dark-blue nodules in the clay.

Beach Pit 6

Site 6 (Fig. 8) was located 35 feet closer to the coffer dam than pits four and five. For the most part pit 6 showed a similar sequence to that of the previous holes. The surficial layer of this site was composed mainly of coarser cobbles but lacked the boulders that occurred on the other beach surfaces. A granular sand supports the surface layer and fines into a medium/coarse sand which was well-sorted. This sand then graded back to a granular sand. A one-inch layer of gray clay then bounded a silty sand below one foot. Eight inches of this sediment then terminated abruptly into a similar one inch layer of gray clay. A sequence of strong brown silty sand then followed for two feet. This sequence then proceeded into a brown gray

Beach pit 3. location: 44 30.707N
64 17.199W



Beach pit 4 location: 44 30.819N
64 17.123W

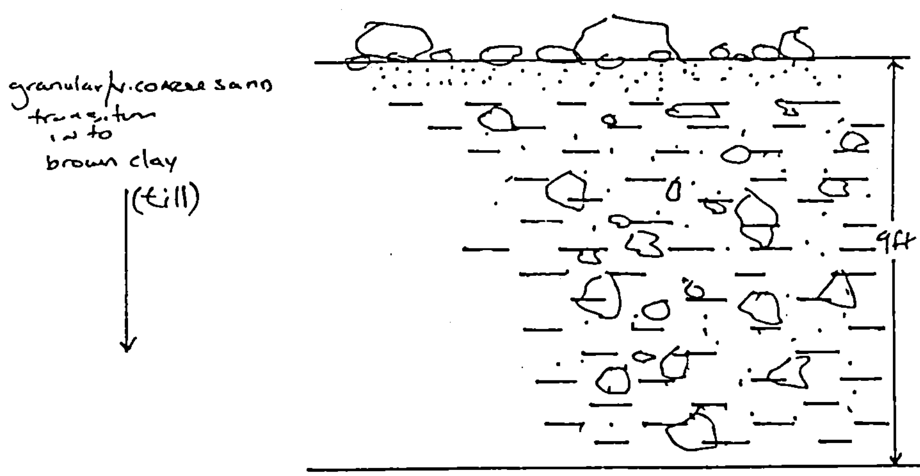
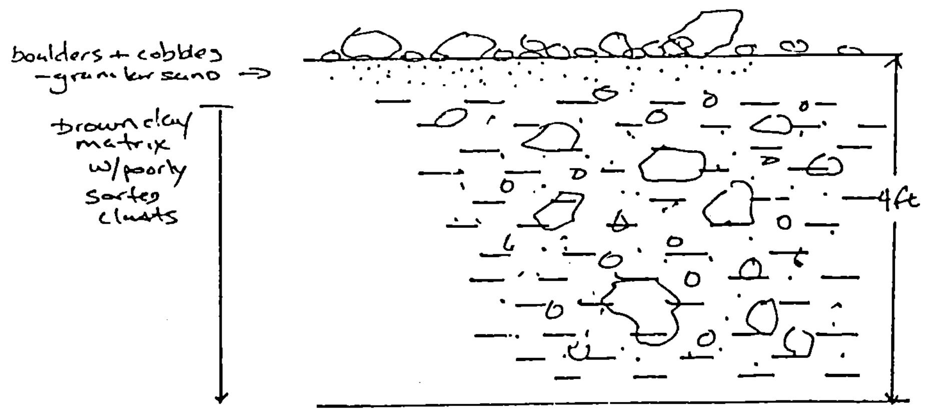


Figure 7

Beach pit 5 location:44 30.826N
64 17.200W



Beach pit 6. location:44 30.827N
64 17.200W

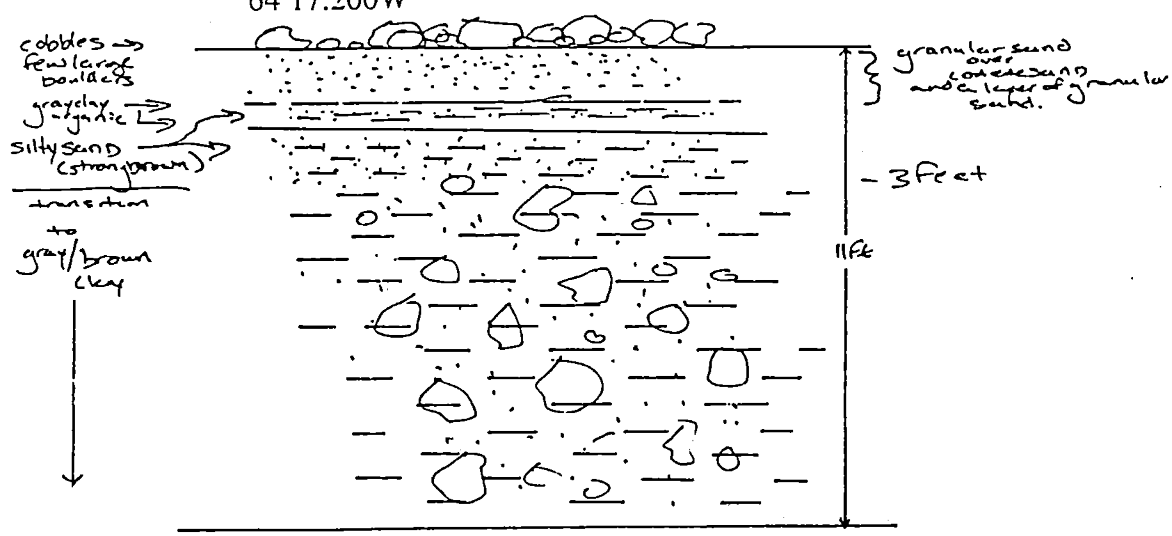


Figure 8

clay mixed with a wide range of grain sizes with cobbles and boulders also present. The clay at five to six feet becomes less permeable to groundwater. The clay from six to eight feet however, becomes more porous allowing water to collect in the hole. These clay deposits continue to the bottom of the hole at eleven feet.

Beach Pit 7

Pit 7 (Fig. 9) followed the same basic stratigraphy of the previous holes with the exception of the top layer. Beneath the sand which supported the cobble/boulder surface, the strata differ from all the other holes. The layer between six inches and three feet consists of a silty sand with sparse gravel and cobbles. The layer was penetrated by vertical penetrations of different colored sediments. A one-to-two inch diameter core of gray clay was surrounded with yellow brown silt which faded into the gray brown clay matrix. These penetrations became narrower as they approached their termini at around three feet. Below this layer, the strata were similar to that observed in pits 3, 4, 5, and 6.

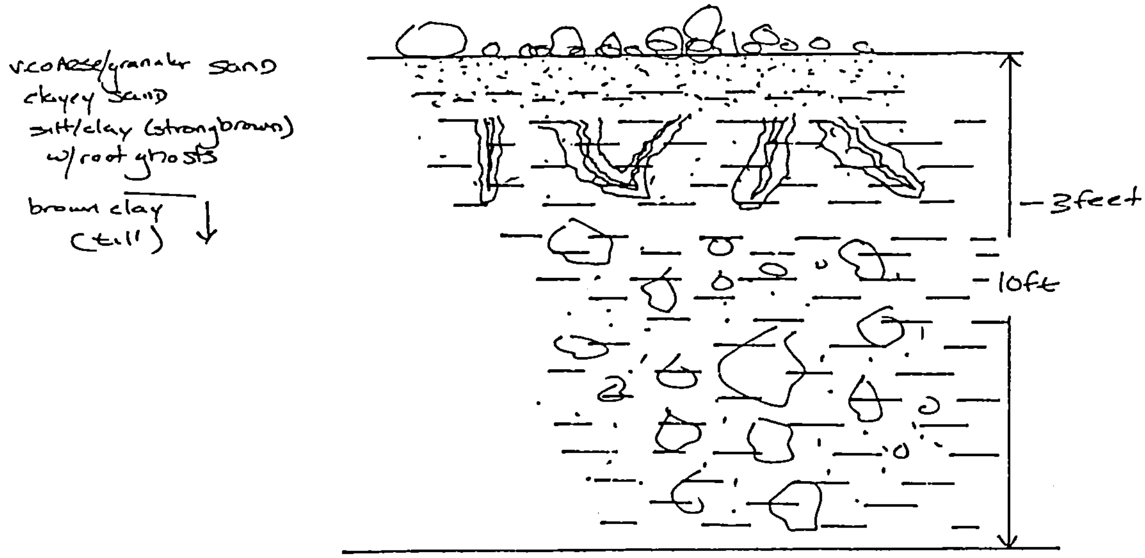
Beach Pit 8

This pit (Fig. 9) was located 130 feet ~~south~~ north-east of beach pit number ~~7~~ 2. The pit was positioned opposite the eastern-most portion of the Oak Island marsh. The sequence in this pit was similar to that of beach pit 2 except that the iron-stained layer occurred between one-and-a-half and two feet and then faded with depth. Similar to pit 2, slate fragments that were oriented horizontally were abundant throughout the sequence. The sand matrix also became finer with depth and with some layers of packed cobbles and gravels. As the pit approached thirteen feet, the sediments became dark brown and smelled of organic material. At thirteen feet, the backhoe struck a one-and-a-half inch layer of peat which overlaid a gray organic layer indicating marsh deposits. Beneath eight inches of gray clay, there was a layer of olive yellow clay. This clay was a saturated clay composed of very fine material with no evident gritty or coarse material.

Summary and Interpretation of beach pits:

The observations made in each of the beach pits show relative sea level in Mahone Bay is rising. This can be deduced from both sedimentologic and geomorphic observations. All of the beach pits display similar shallow deposits that illustrate shoreline working of glacial sediments. In addition, the eroding banks along the eastern most portion of the island coupled with the former upland

Beach pit 7. location:44 30.768N
64 17.125W



Beach pit 8. location:44 30.738N
64 17.418W

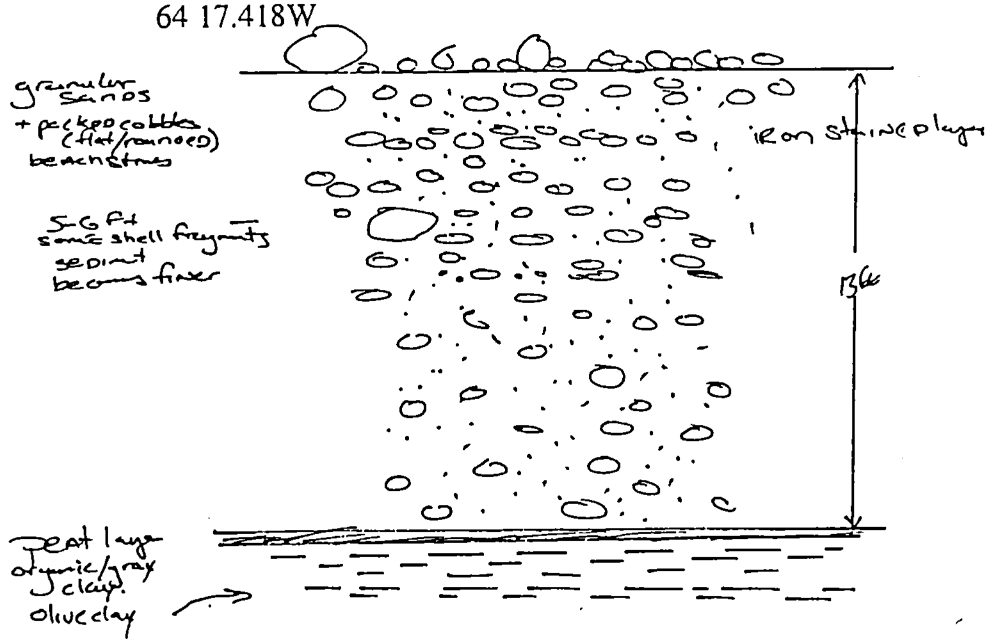


Figure 9

deposits in the surface of pit 7 demonstrate the effects of shore line submergence. Lastly, the occurrence of peat beneath the deposits in pits 2 and 8 show that a marsh surface once existed at a lower elevation than present day.

The shoreline of Oak Island reflected reworking of glacial sediments in the top foot of the beach. All of the deposits on the shoreline are covered with cobbles and boulders which create a shield over the thin sand layer below. These cobbles and boulders are less likely to be transported compared to the finer sand, silt, and clay size fragments of the glacial till which composes the glacial deposits known as drumlins. As the water level rises and inundates the shoreline, the finer portions of these deposits are gradually eroded into the bay leaving behind the sand, cobbles, and boulders. High energy storms probably remove most of the sands from the immediate surface of the beaches, but the remaining cobbles and boulders remain on the surface and become more concentrated as more fines are eroded. As the cobble and boulders become more numerous, the sands become better protected and form a layer beneath the surface. In most cases, this surface fines into glacial material within six inches to a foot of the surface. The sorting of the residual deposits is poor as the heavier/larger fragment are left in place. Since this is glacial material, sand sized sediments are subangular in shape.

The condition of the sub-aerial shoreline in connection with the nearby deposits also indicates the rise of the water level on the island. An eroded bank is present on the eastern portion of Oak Island. In this area, a one-to-two foot scarp separates a vegetated upland from the rocky shore line. The scarp is an undercut bank with evidence of trees fallen due to the erosion of their root system from the receding upland. In pit 7, the penetrations just below six inches indicate the past presence of root systems of land-dwelling vegetation in that area. Pit 7, located 15 feet towards the water from the bank, was once upland area. Rising water levels and periodic high waters due to storms facilitate the erosion of this portion of the shore. The color of the upper deposits at this pit also suggest the formation of a soil horizon indicating a vegetated terrestrial environment. The progression of the faded yellow brown sediment followed by darker sediments indicated leaching and oxidation at the surface.

A similar horizon is present at the top of pit 6. This hole, however, is located in an area which has been influenced heavily by digging in the past. The upper layers above the brown glacial clay may have developed both from soil formation and the deposition of material eroded off the steep slope adjacent to this site. Most of that hillside is deforested and may have been heavily used during the extensive work done around the Coffer dam. The yellow-brown sediments were probably eroded off the hillside and then covered with organic material reflected in the dark gray layers interleaving this layer.

Presence of peat layers at depth show that the adjacent marsh surface was at one time at a lower elevation. The peat layers would have been deposited at the sediment water interface in that environment. Gradual water level rise as well as high energy storms could deposit the barrier sediment into the marsh pushing it farther into the island.

Finally, the sediments observed along the shoreline as well as the shoreline morphology show that the shoreline of Oak island is receding. Shoreline recession is due to relative sea-level rise (land sinking and sea-level rising). Another variable in this picture concerns the limestone bedrock beneath this portion of the island. Through time limestone will dissolve if conditions favor its dissolution. Karst regions often experience either catastrophic or gradual subsidence due to solution of the limestone rock which could yield the apparent affect of a rising water level. A similar shore line assessment of the western portion of the island may yield different information as it is underlain by slate which is not likely to dissolve at depth leading to land subsidence.

Analysis of wood and vegetation samples

During the field investigations, several samples were acquired for further investigation, including wood samples, fibrous material resembling coconut fibre, and peat from the beach pits. These samples were investigated using Scanning Electron Microscopy (SEM), Accelerated Mass Spectroscopy (AMS), electron scanning for elemental composition, and visual methods. These methods are the most sophisticated methods available for investigation of carbon and related materials, for purposes of age-dating, source determination, and composition detection. Samples are described in Table 6. Methods for radiocarbon dating, plus a description of their utility and accuracy are also presented in Attachment D, with the full data reports from the National Ocean Sciences AMS Facility at WHOI (NOSAMS). The NOSAMS provides markedly improved accuracy for radiocarbon dating compared to methods used previously by searchers; it also can date samples of much smaller mass (including the ability to date open ocean water samples!).

Peat samples:

Peat samples were taken from beach pits on the island, as described above. Two samples were obtained: one from Beach Pit 2 (Fig. 6) at a depth of approximately 8 feet below MSL, and the second from Beach Pit 8 (Fig. 9) at a depth of approximately 10 feet below MSL. Both beach pits were along the barrier beach of South Shore, separating the marsh area from Mahone Bay waters. Beach Pit 2 peat has a radiocarbon age of 1940 years before present (ybp; about AD 50). Beach Pit 8 peat has a radiocarbon age of 2340 ypb, or approximately BC 345 (at the time of Alexander the Great's childhood in Macedonia).

Examination of the peat makes it difficult to identify visually, but we tentatively interpret it to be brackish water peat until further examination. If we assume this peat was deposited at or above sea level at the time, we can estimate the lower limit for relatively sea-level rise at this area. Since we are in a region of complex glaciation, where the land level is still adjusting to the glacial loading and unloading, we must speak only of relative sea level, not absolute sea level. At Mahone Bay, in-place deposits will mark locations only of relative sea-level change.

The beach pit 2 sample yields a minimum relative sea-level rise of 1.25 mm/year (about 0.4 feet per century), whereas the beach pit 8 sample yields a relative sea-level rise of 1.3 mm/yr (about 0.43 feet per century). Both samples yield consistent rates of relatively sea-level rise. Though abundant uncertainty exists regarding the global absolute sea-level rise rate for the past few centuries, measurements and analysis indicate a range of about 1-2 mm/yr. The present samples are within this limit, indicating that glacial isostatic adjustment due to loading and unloading of the crust by glaciation, may be small for the past 2000 years.

If the peat samples represent deposits from above mean sea level, rather than at sea-level, the rate of relative sea-level rise will be a little faster. However, the rates will increase only to about 1.6 mm/yr or so, so this uncertainty does not alter our major conclusions.

The implications of this rate of relative sea-level rise are important for the searchers. If relative sea-level rise has been about 0.43 feet per century, then at the time the coconut fibres may have been deposited (some 800 to 1100 years before present; see Table 6), then sea level was also at a lower stand: some 3.4 to 5 feet below present levels. Thus, evidence left by people working at the site during this period must be referenced to a sea level lower by some 5 feet.

Table 6
Radiocarbon-dated samples
(see Attachment D for details)

Receipt	ID	Description	Location	Age (ybp)*	Age Error
10164	OI-ICF1	Seaweed	From beach surface along Smith's Cove, 25/7/95. Sampled by DGA and BG. Fibrous, fibre-like seaweed mat.	Modern	
10165	OI-W6	Wood	Provided by Dan Blankenship: wood from borehole 10x at 165'.	120	35
10166	OI-W7	Wood	Provided by Dan Blankenship: wood from 10x (?)	75	30
10167	OI-5-CF3	Coconut fibre	Dug from Smith's Cove by DGA and Dan Henskee, 27/7/95	1140	30
10168	OI-3-CF2	Coconut fibre	Provided by Dan Blankenship	765	35
10169	OI-BP-2	Peat	Dug from Beach Pit 2 at depth of approximately 8 feet below MSL. Along south shore barrier beach, across from the swamp.	1940	40
10170	OI-BP-8	Peat	Dug from Beach Pit 8 at depth of approximately 10 feet below MSL. Along south shore barrier beach, across from the swamp.	2340	35

*ypb= years before present

Since Smith's Cove now is about 1-2 foot below MSL, what is now Smith's Cove would have been above water during the period 800 to 1100 years before present. The shoreline at that time would have been seaward of what we now view as Smith's Cove. Thus, searcher's seeking "flood tunnel" outlets and inlets would have to concentrate on areas farther seaward than where the search has focused the past century.

Seaweed sample:

A sample of recent seaweed was collected from the storm high tide mark along Smith's Cove. This seaweed was fibrous, and resembled what some may perceive as coconut fibre. The radiocarbon age was modern, confirming its recent origin. Comparison of this seaweed, however, with the purported coconut fibre, showed it to have different morphology than the coconut fibre, and hence of no interest in interpreting coconut fibre history.

Wood samples:

Two samples of wood were radiocarbon dated. Both samples were presented to Oak Island Discoveries by Dan Blankenship. Their provenance is unclear. We don't know if the sample came from a log, or from worked wood. We also don't know if this was the outer portion of the wood, or the inner core. Consequently, the dating of these samples were not expected to provide much of interest. Both samples of wood dated to modern times, about 100 years ago.

We can compare these radiocarbon dates with previously reported dates:

• Woods samples from Nolan's shaft shows a recent date, but one which is ambiguous because of the non-uniqueness of the radiocarbon curve (also from Beta Analytic, in 1993).

• Another wood sample was dated by Geochron Laboratories and reported on 3 June 1969. This wood had a date of 1575 AD ± 85 years.

It is clear the two samples we were given had no similarity to the Geochron lab sample.

Coconut fibre:

Coconut fibre has taken on some aura of importance at Oak Island for several reasons:

• It was found as a filter fabric, along with seagrass, at the Smith's Cove outlets of the flood tunnels, reported by previous searchers.

• It was previously dated and stated to be old: A letter from Richard C. Nieman of St. Louis Missouri dated 6 October 1993, reports a date on coconut fibre of 1229 AD ± 70 years. This sample was obtained by David Tobias (or perhaps Dan Henskee, see Nieman letter of 27 September 1993) from Smith's Cove, and reported by Beta Analytic, Inc., of Miami, Fl. A second test of coconut fibre showed an age of 1278 AD ± 60 years (about 715 ypb). Thus, coconut fibres are the one material which have been verified to be old.

• Coconut fibre was found underneath logs unearthed at Smith's Cove in the 1970's by Dan Blankenship, and hypothesized to be original and old.

We therefore dated two coconut fibre samples. The first, receipt 10168 (OI-3-CF2) was provided by Dan Blankenship to Oak Island Discoveries, and presented to

WHOI to date. The age was determined to be 765 ypb ± 35. This age is indistinguishable from the age of the samples dated by Beta Analytic and reported above. We hypothesize we must have dated a subsample of the same material.

The second coconut fibre came from just below low tide level within Smith's Cove. It was excavated by Dan Henskee in the presence of D. Aubrey and others on 27 July 1996. After dewatering the site where Henskee knew the sample to be located, Dan dug down about 8 inches to found the fibre which we dated. We have no knowledge of how the fibre came to the position where Henskee located it; only that we sampled it on that day.

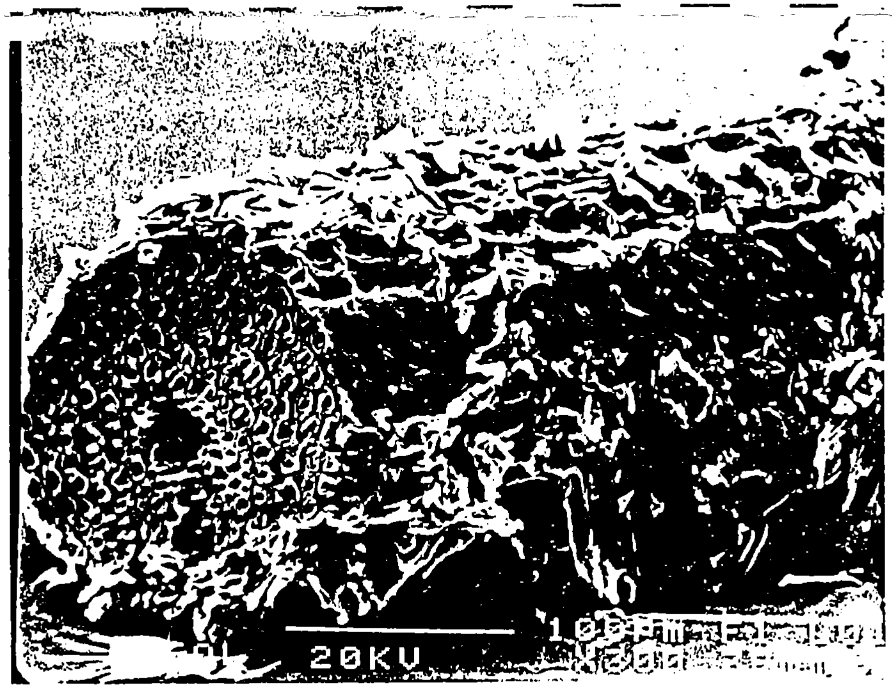
This second coconut fibre sample (receipt 10167 and ID OI-5-CF3) dated to 1140 ypb, ± 30 years (or approximately AD 855).

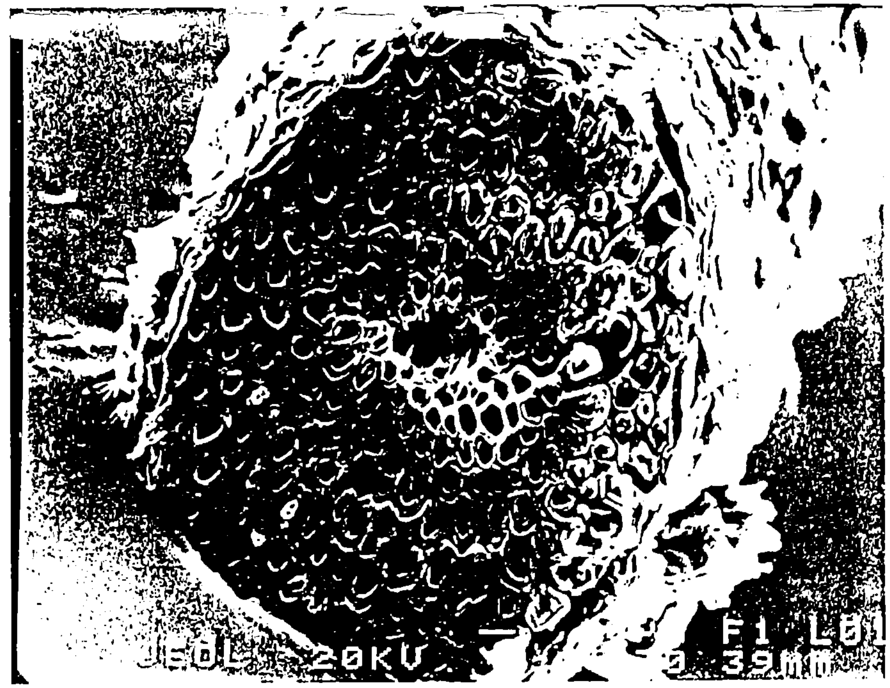
In order to determine whether this material indeed was coconut fibre, we consulted some experts. Unfortunately, the fibre was heavily decomposed, consisting of only about 5% carbon by weight, a low percentage for most vegetative materials. We examined the photographs by Scanning Electron Microscope, a sophisticated means to examine materials at very fine scale. SEM work was performed by xxxx of the U.S. Geological Survey in Woods Hole, MA. Fig. 10 shows some SEM photo-micrographs of sample OI-5-CF3.

We sent the SEM photo-micrographs and portions of the original fibre sample to two palm experts: Scott Zona of the Fairchild Tropical Garden, in Miami, FL, and Prof. (Emeritus) Natalie Uhl, of Cornell University. Correspondence with these two individuals is contained as Attachment E.

Dr. Zona thought the fibers might be husk fibers of a coconut, but his comparison with modern fibers was inconclusive. Dr. Uhl has been of great assistance, but she is still continuing her investigation. She concluded that the SEM photo-micrographs do resemble fibrous bundle sheaths in palm stems. However, without the full bundle (including the xylem to check on the vessel structure), she could not be conclusive. She does not believe the material can be identified to genus and species. She is currently working with a colleague, Dr. Francisco Guanchez from Venezuela, who is a specialist on Leopoldinia, a genus long exploited for fiber. They are examining the materials at present at Cornell.

For comparison, we have taken SEM photo-micrographs of the coconut fibre at Oak Island, as well as mesocarp coconut fibre from Cocos nucifer, a coconut commonly found in the tropics (Fig. 11). Though notable similarities exist between the two types of fibres, we await final confirmation from the palm and coconut specialists.


20KV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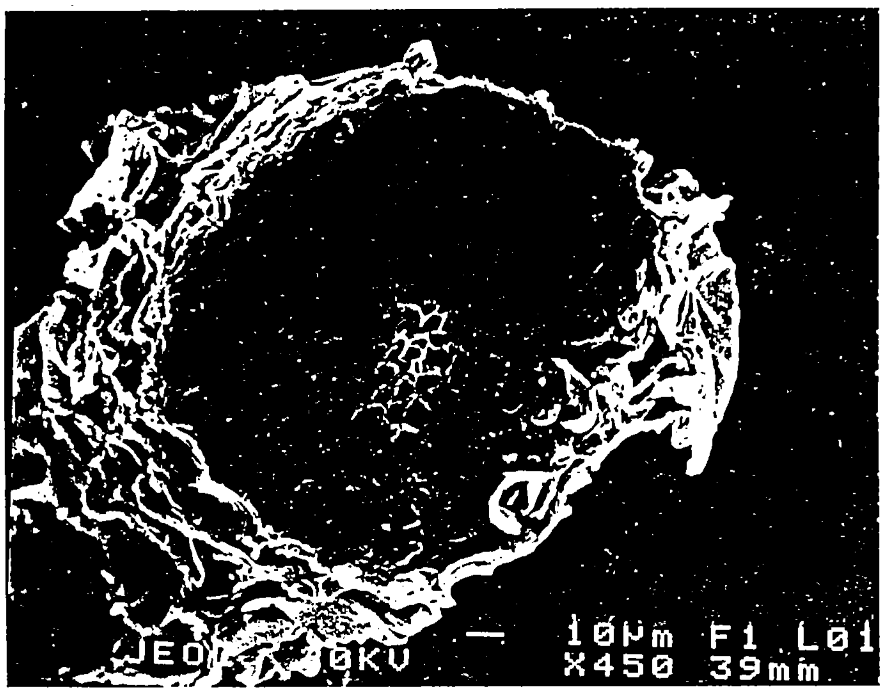
39mm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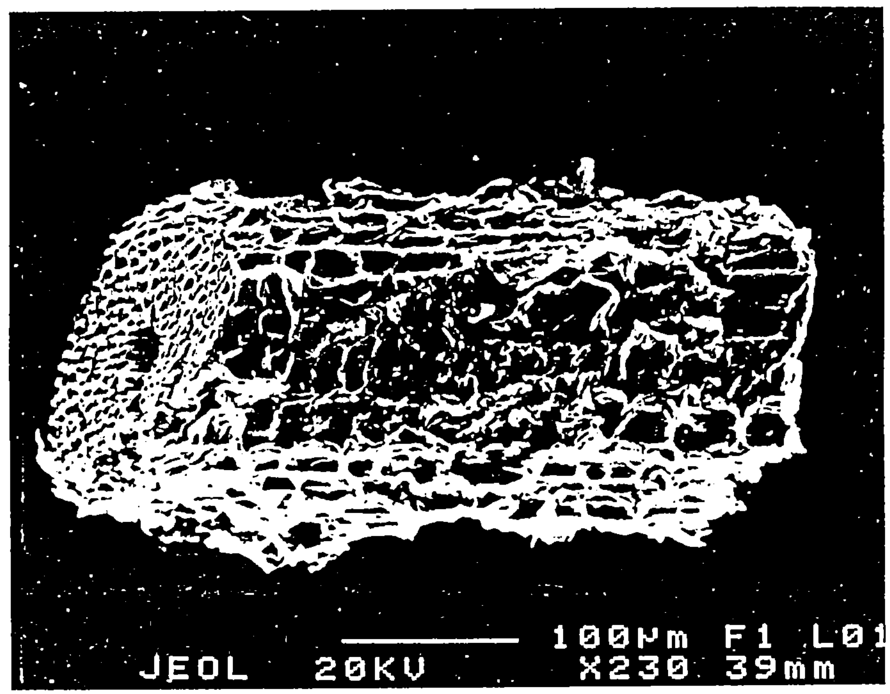

100µm F1 L01
JEOL 20KV X230 39mm

The coconut fibre, if verified as we believe it will be, may have reached Oak Island through four primary pathways:

i) "Planted" on the island by previous searchers

ii) Natural transport by Gulf Stream and inshore currents

iii) Dunnage discharged at Oak Island by a previous ship

iv) Brought and used by ancient voyagers for flood tunnel purposes

No evidence at present allows us to discount pathway i) above, other than Triton associates claim of finding the fibre; we cannot discount previous searchers or others "planting" the material.

We are unfamiliar with other instances where the Gulf Stream has transported a significant amount of coconut fibre intact to a single location. We are currently researching this factor, with help from Natalie Uhl and her colleagues

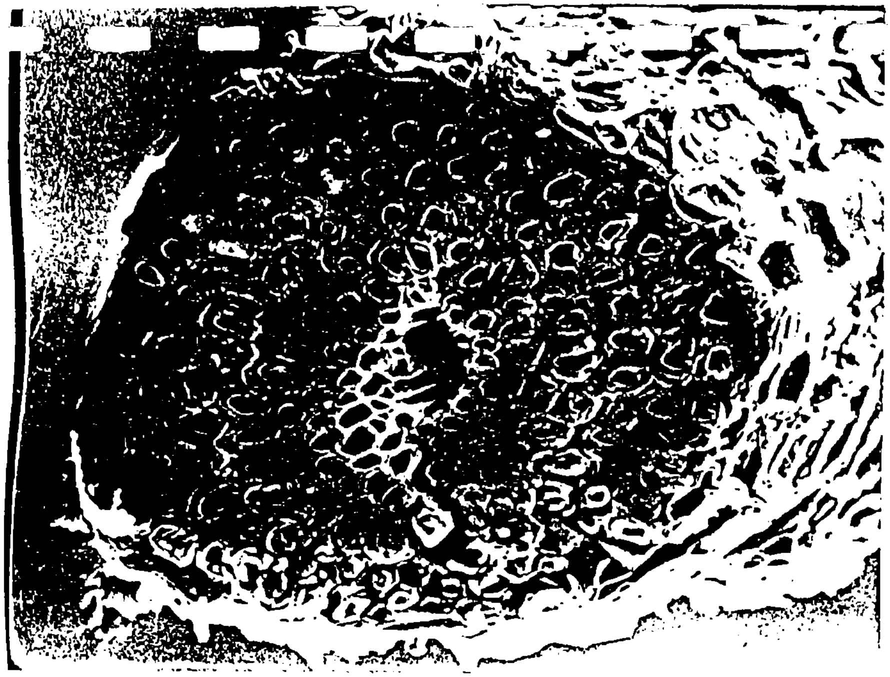
We cannot discount the potential use of fibre as dunnage (iii), from a ship previously using Oak Island. For instance, a ship involved in the wood (oak) trade might have come to the island with this dunnage. Why the fibre would be so old is another matter.

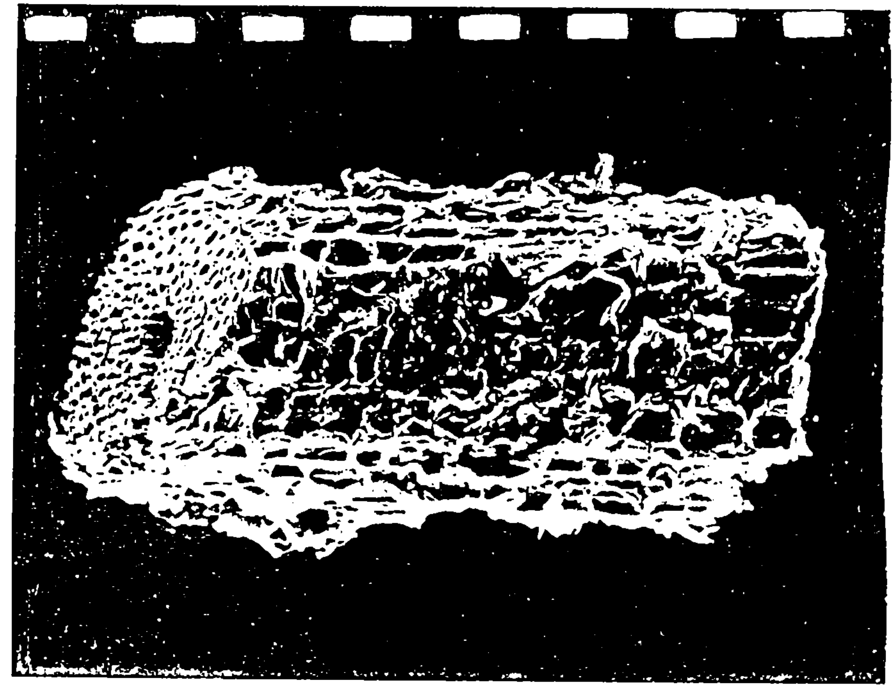
Finally, we cannot discount the final pathway: use by ancient voyagers. Perhaps the only way to determine whether this was an appropriate pathway or not is to discount the other three pathways. We are examining pathway ii) at present; clarification of other pathways is certain to be more difficult.

Future Activities

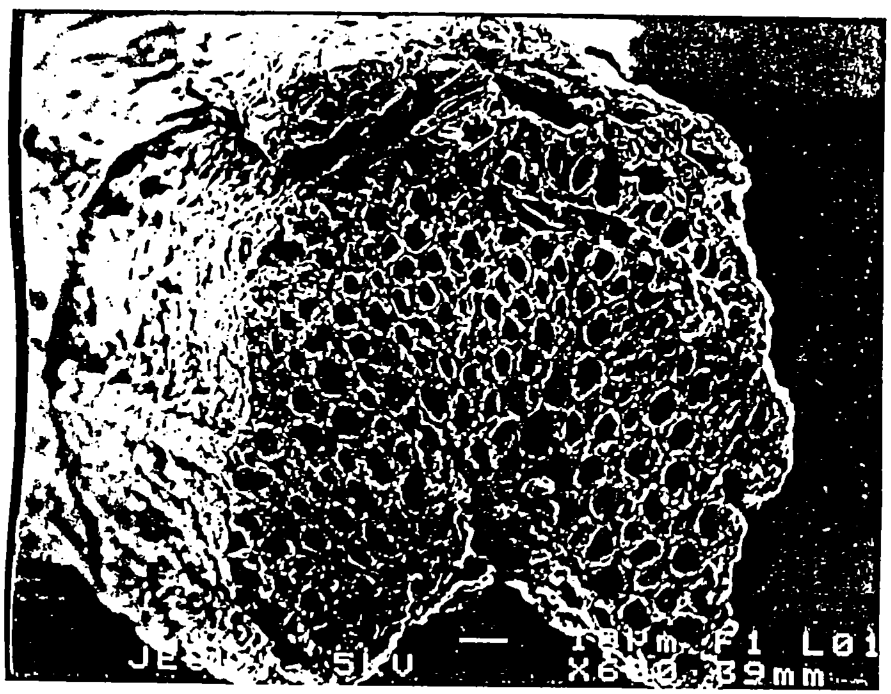
We have provided in independent correspondence a list of items which we believe will help clarify the mystery of Oak Island, including elements to address the following:

- Clarifying the stratigraphy on the island, by proper sampling of boreholes on the island at five or more locations.
- Examining water within the clay and deep bedrock for geological evolution by use of various isotopic tracers (nitrogen, oxygen, etc.)
- Examining records of old trade routes dating to about 1000 AD, to determine whether or not this area was on ancient trade-routes
- Examining the geology of the offshore area using non-intrusive methods (sub-bottom profiling) to determine if the stratigraphy offers clues about the geological evolution of the island.

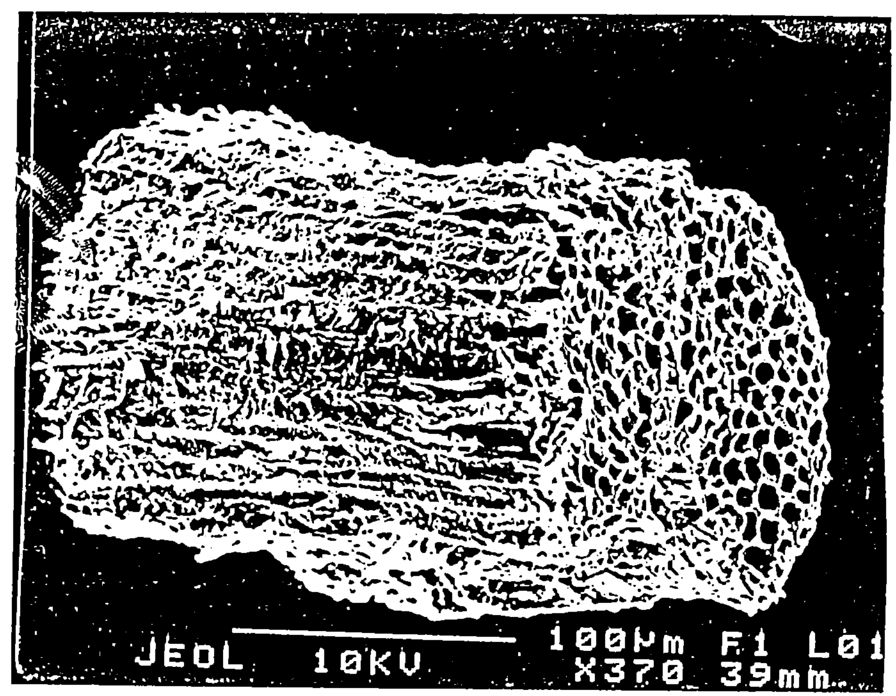




OAK ISLAND



OAK ISLAND



• Archaeological investigation of Smith's Cove and other potential historical and pre-historic sites.

• Photographic investigation of boreholes into bedrock, including 10-x (if possible), new borings, plus borings near 24/8.

Acknowledgments

The WHOI team would like to thank Mr. Mugar and associates for giving us the opportunity to perform this investigation. We also would like to thank the field crew, including Mr. and his associates, for helping with logistics during the frenzied field operations. We would like to thank Mr. Dan Henskee for his cooperation and help during our field operations, though he lost the wager on the geology of the barrier beach fronting the swamp. We also would like to thanks Mssrs. Dan Blankenship and Fred Nolan for discussing their views and ideas on the island with us. We would like to thank the National Ocean Sciences AMS Facility (in particular, Drs. Robert J. Schneider and Ann P. McNichol) for their assistance in the radiocarbon dating; and XXXX of the United States Geological Survey, Atlantic Marine Branch in Woods Hole, Massachusetts), for their help with the SEM work.

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Attachments

Attachment A: Experiment Plan for Oak Island

Experiment Plan For
Oak Island
22-30 July 1995

Aubrey/Gallo

Personnel:

David Aubrey (Team B)
Ben Gutierrez (Team B)
Steve O'Malley (Team A, diving)
Quin Robertson (Team A)
Wayne Spencer (Team A)

Operational Dates:

Field Work; 21-30 July 1995

Equipment:

32' boat (locally owned)
IBM computer (3ea)
Diving gear
DGPS
Klien SS sonar
Odom Fathometer
Fluorometer
SeaBird CTD
Miscellaneous tools and tool boxes

21 July 1995 (Friday):

Tasks to be accomplished;
1. Travel to Oak Island

Personnel;
Team A
Team B (Ben only)

13:00
Team A,B Travel to Oak Island in Van with gear (Via Portland to Yarmouth ferry)

22 July 1995 (Saturday):

Tasks to be accomplished;
1. Inspect boat
2. Check into hotel

Personnel;
Team A
Team B (Ben only)

09:00 Team A	Arrive Yarmouth Nova Scotia on Ferry
15:00 Team A	Arrive Oak Island
15:00 - 17:00 Mugar Team, Team A	Meet at hotel, inspect boats, meet captains
18:00 Mugar Team, Team A	Dinner at hotel, firm up plans for tomorrow

23 July 1995 (Sunday):

Tasks to be accomplished;
1. Load boats
2. Check out equipment

Personnel;
Team A (Quin, Wayne)
Team B (Ben)

13:00 Team A, Team B	Load boat and check out equipment
18:00 Team A, Team B	Dinner and firm up plans for tomorrow
19:00 Team A, Team B	Finish checking out equipment and installations on boat

25 July 1995 (Tuesday):

Tasks to be accomplished;
1. Filming
2. Begin dye experiments (select two wells and place rhodamine in wells).
3. CTD transects with fluorometer offshore (as close to shore as possible). Search for dye and fresh water sources. Mark sources for future diving verification.
4. Survey beaches, determine locations for sampling for holes to search for eel grass and coconut fiber.
5. Log bathymetric and side scan sonar data

07:00 Breakfast

08:00

Team A	Begin dye tests in wells; select two wells and place rhodamine in wells.
Team B	Survey beaches, determine locations for sampling for holes to search for eel grass and coconut fiber.
Mugar Team	Filming and drilling

10:00

Team A	Do CTD transects with fluorometer offshore: as close to shore as possible. Search for dye and fresh water sources. Mark sources for future diving verification. Acquire bathymetry and SS sonar data.

18:00 Dinner

Team A,B, and Mugar Team	Compare notes over dinner. Firm up plans for tomorrow.

20:00

Team A (Wayne)	Pick up Steve O'Malley at Halifax airport

26 July 1995 (Wednesday):

Tasks to be accomplished;
1. Filming
2. Continue fluorometer tests in nearshore waters.
3 Beach pits dug: search for wood fragments/datable materials, coconut fibers

Personnel;
Team A
Team B
Mugar team

06:00 Breakfast

07:00

Team A	Continue fluorometer tests in nearshore waters. Collect bathymetry/SS sonar data.
Team B	Beach pits dug: search for wood fragments/datable materials, coconut fibers
Film crew	film in the AM

18:00 Dinner

Team A, Team B, Mugar Team	Compare notes and firm up plans for tomorrow

27 July 1995 (Thursday):

Tasks to be accomplished;
1. Side-scan and depth surveys around the island; search for eelgrass offshore
2. Continue with beach pits, morphological studies, studies of u-shaped structure, etc. for radiocarbon sampling.

Personnel;
Team A
Team B

06:00 Breakfast
07:00
Team A — Side-scan and depth surveys around the island; search for eelgrass offshore
Team B — Continue with beach pits, morphological studies, studies of u-shaped structure, etc. for radiocarbon sampling.
12:00
DGA — Departs for Woods Hole
18:00 — Dinner
Team A,Team B — Compare notes at dinner. Firm up plans for tomorrow.

28 July 1995 (Friday):

Tasks to be accomplished;
1. Dive on anomalies if found; also dive on eelgrass offshore.
2. Repeat dye test; insert dye in AM
3. Monitor for dye using fluorometer.

Personnel;
Team A
Team B

06:00 Breakfast
07:00
Team A — Dive on anomalies if found; also dive on eelgrass offshore.
Team B — Repeat dye test; insert dye, monitor for remainder of the day.
15:00
Team A (Wayne, Steve) — Take Steve to airport. Watch decompression tables Steve.

29 July 1995 (Saturday):

Tasks to be accomplished;
1. Retrieve tide gauges; download data
2. Unload boat and load van

Personnel;
Team A - Quin, Wayne
Team B - Ben

06:00 Breakfast, check out of hotel
07:00
Team A, Team B	Retrieve all tide gauges.
09:00
Team A, Team B	Unload boat and load gear into Van.

30 July 1995 (Sunday):

Tasks to be accomplished;
1. Travel back to Woods Hole

Personnel;
Team A - Quin, Wayne
Team B - Ben

06:00 Check out of hotel
06:30
Team A, Team B	On the road to Yarmouth
09:00
Team A, Team B	Arrive Yarmouth
10:00
Team A, Team B	On Ferry to Portland, Maine
20:00
Team A, Team B	Arrive Portland, Maine
02:00 (31 July)
Team A, Team B	Arrive Falmouth, MA

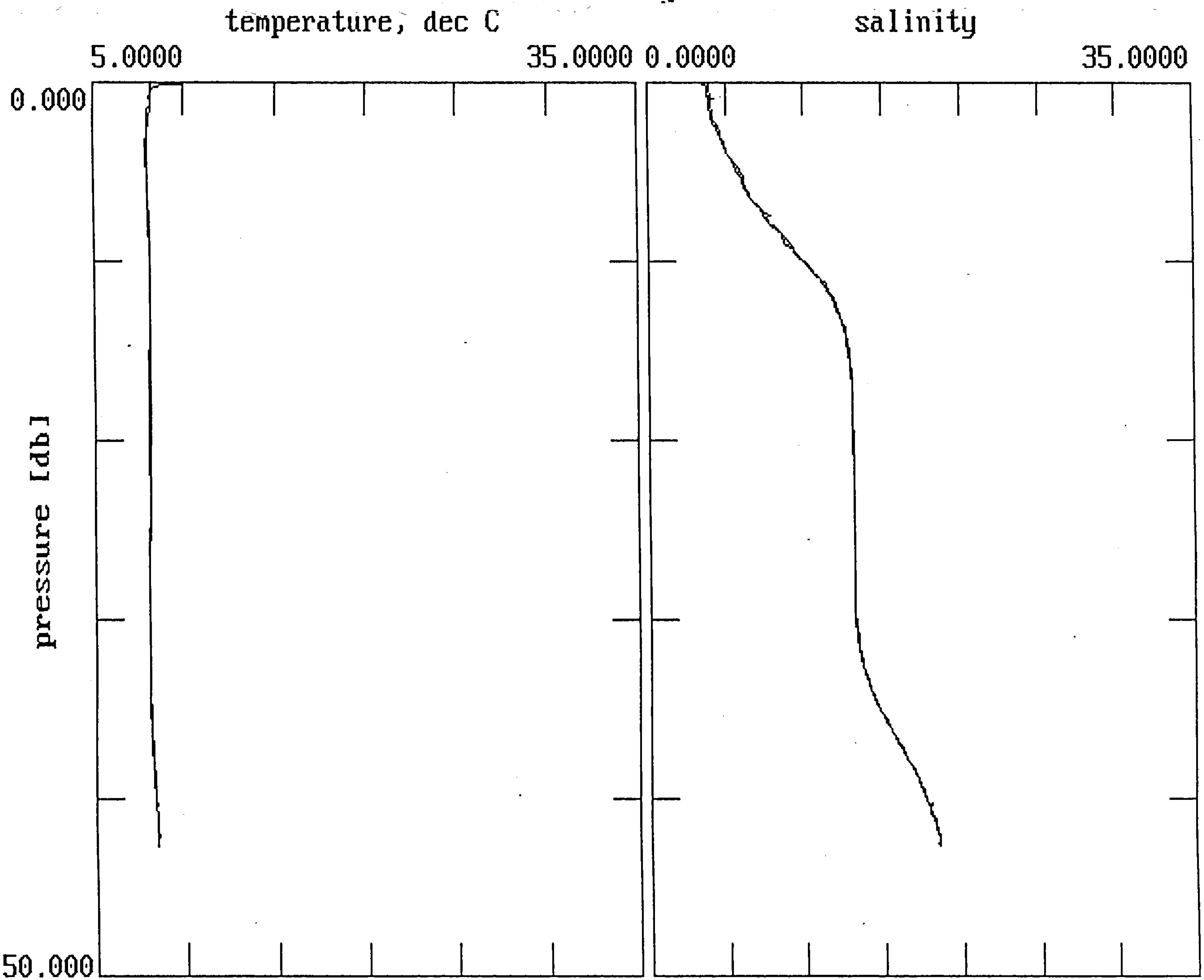
Tides
22-29 July 1995, Mahone Bay, NOVA SCOTIA
3 hours and 20 minutes before Boston, MA (rise =4.5 feet)

Date	high (ADT)		low (ADT)	
	A.M.	P.M.	A.M.	P.M.
22 (Saturday)	05:53	18:10	11:47	
23 (Sunday)	06:48	19:01	00:35	12:40
24 (Monday)	07:38	19:48	01:26	13:28
25 (Tuesday)	08:24	20:32	02:11	14:14
26 (Wednesday)	09:07	21:13	02:52	14:57
27 (Thursday)	09:46	21:53	03:32	15:39
28 (Friday)	10:24	22:32	04:10	16:20
29 (Saturday)	11:02	23:11	05:27	17:42

Sunrise and Sunset (Boston MA)
24-29 July 1989

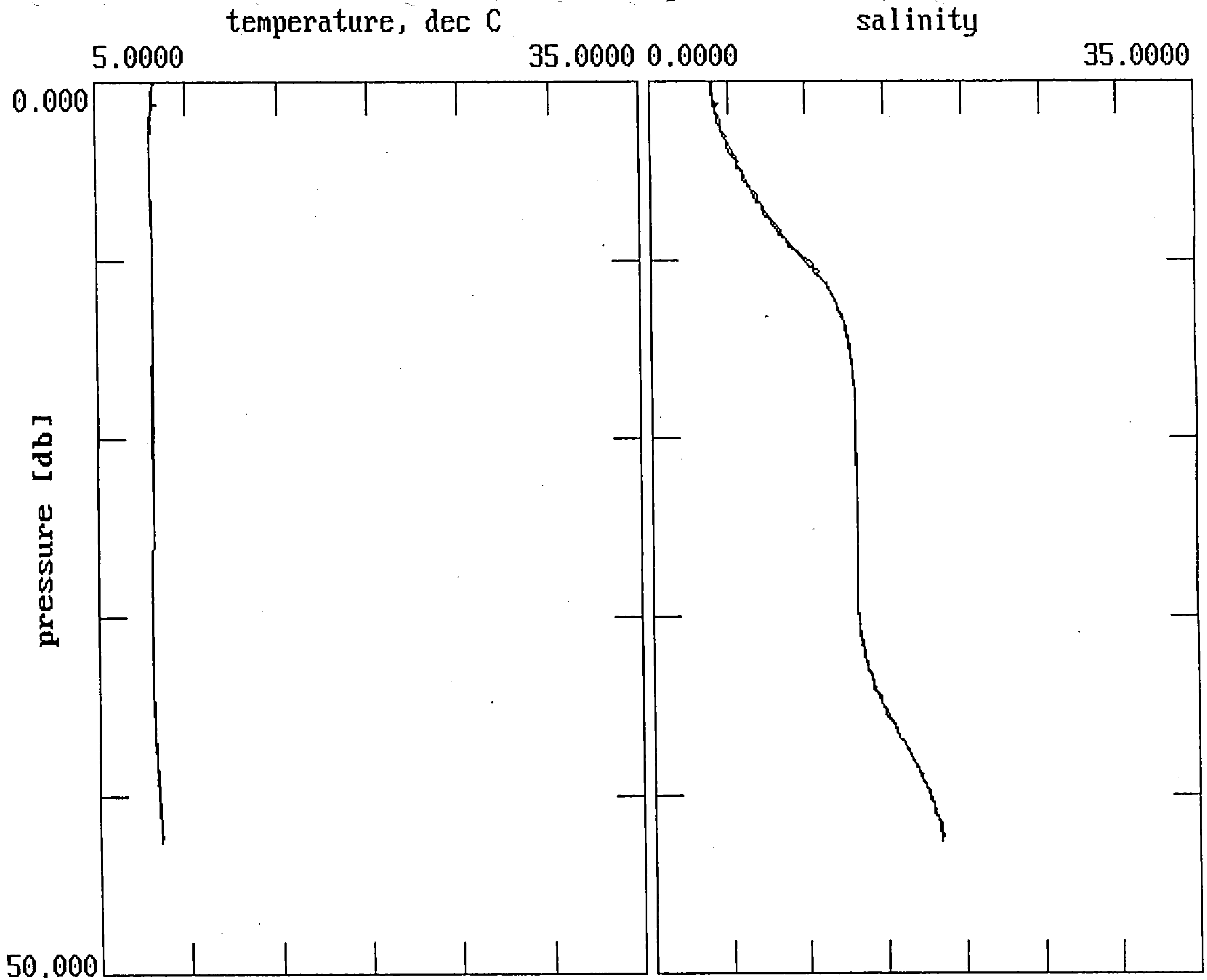
Date	Sunrise (ADT)	Sunset (ADT)
22 (Saturday)	06:21	21:09
23 (Sunday)	06:22	21:08
24 (Monday)	06:23	21:07
25 (Tuesday)	06:24	21:06
26 (Wednesday)	06:25	21:05
27 (Thursday)	06:26	21:04
28 (Friday)	06:27	21:03
29 (Saturday)	06:28	21:02

Attachment B: CTD well data.

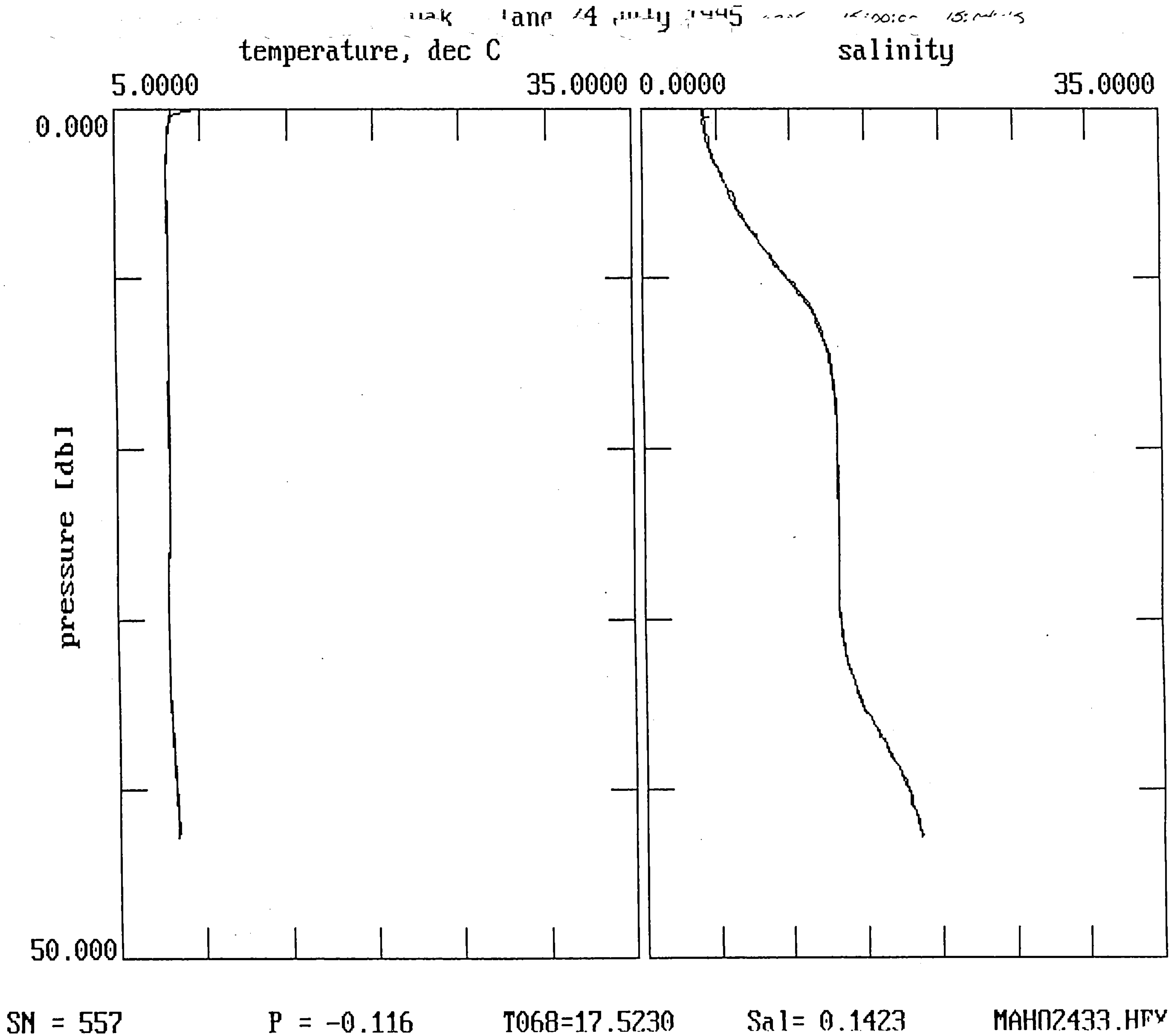


SN = 578   P = -0.545   T068=12.7077   Sal= 0.0727   MAHO2423.HEX

Oak Island 24 July 1995



SN = 585 P = -0.142 T068=15.3820 Sal= 0.0850 MAHO242A.HEX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salinity
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35.0000
0.000
50.000
pressure [db]
SN = 557
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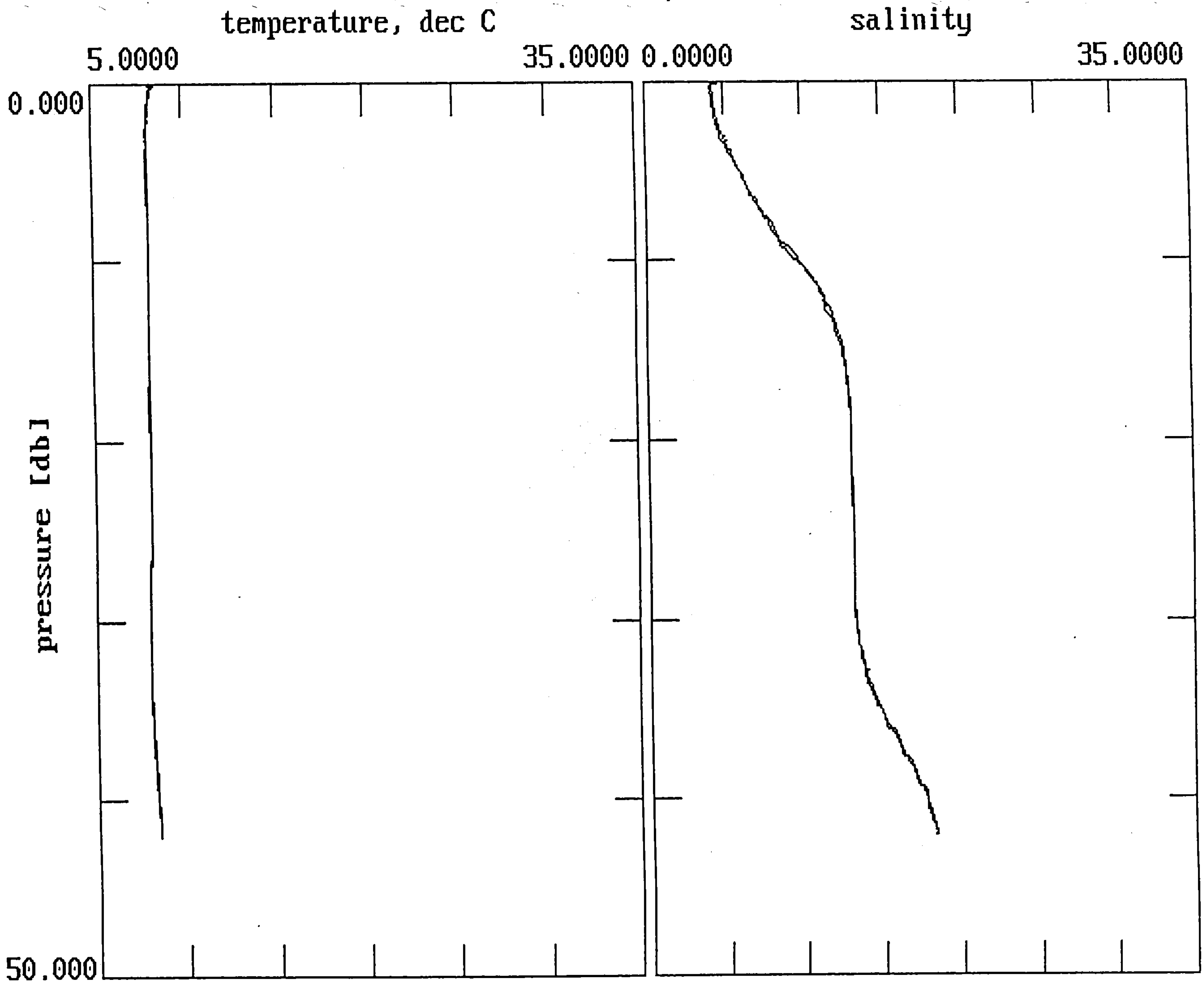
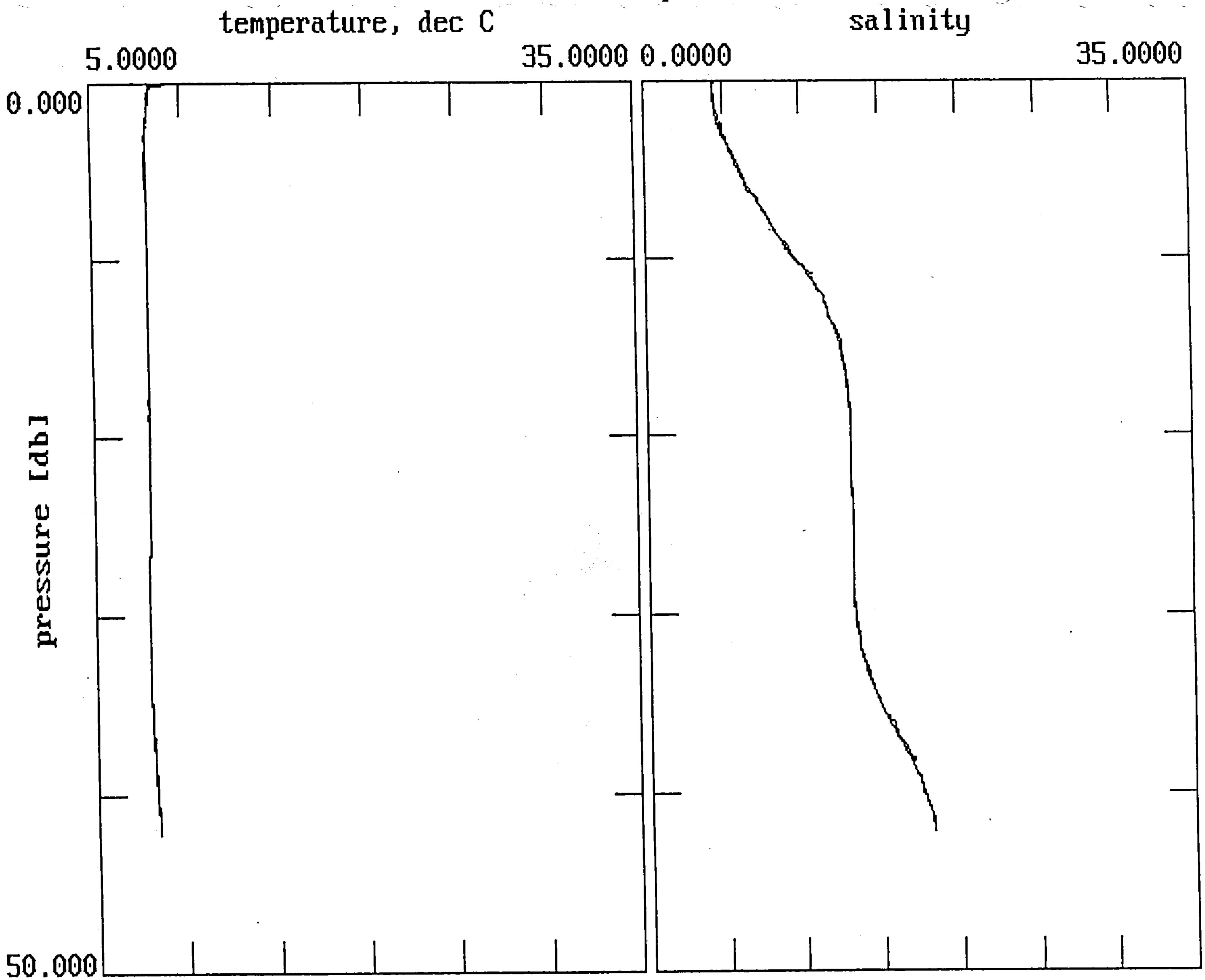
T068=17.5230
Sal= 0.1423
MAH02433.HFY

Hak . land 24 July 1995 9205 15:52:30- 16:0 8

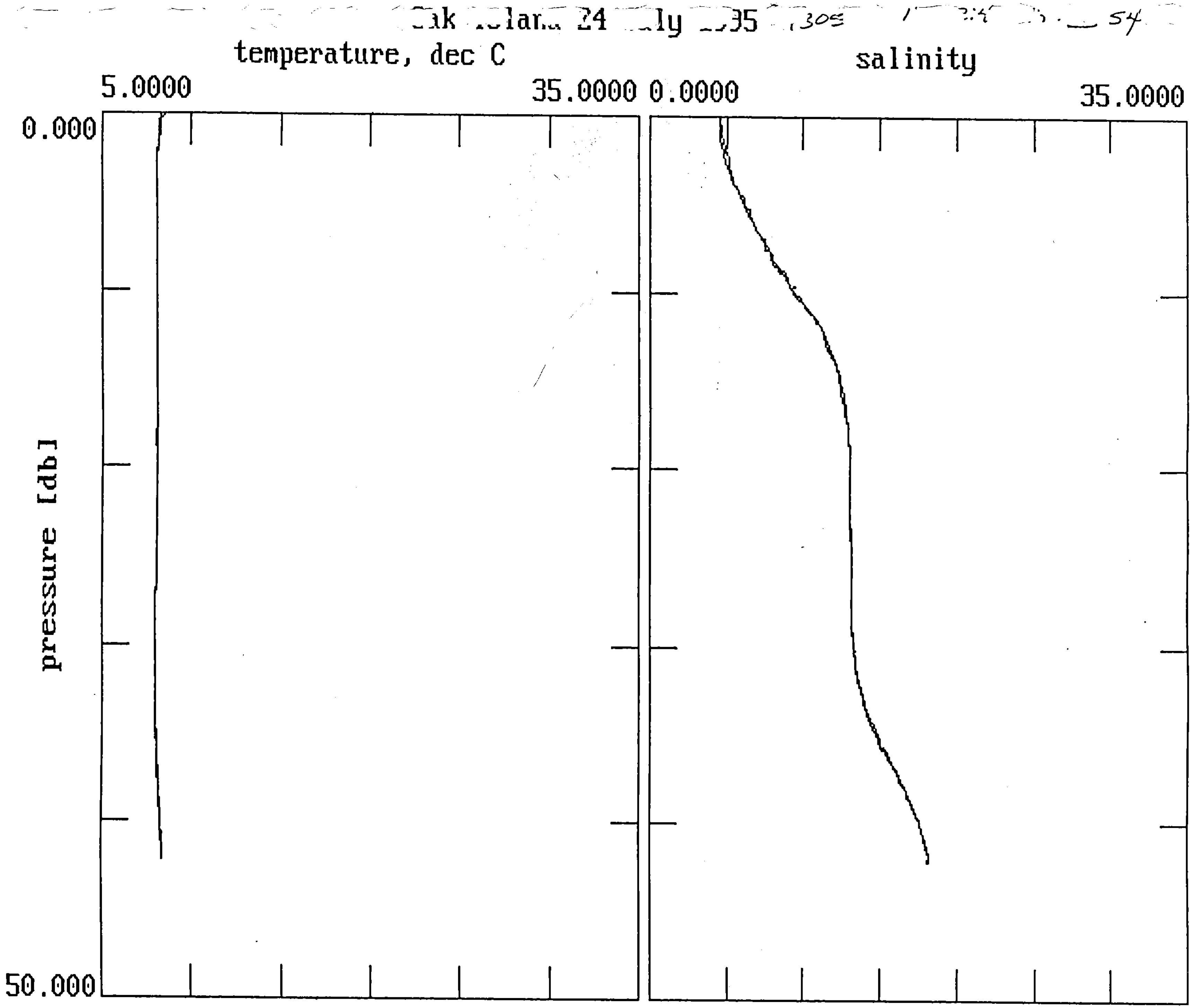


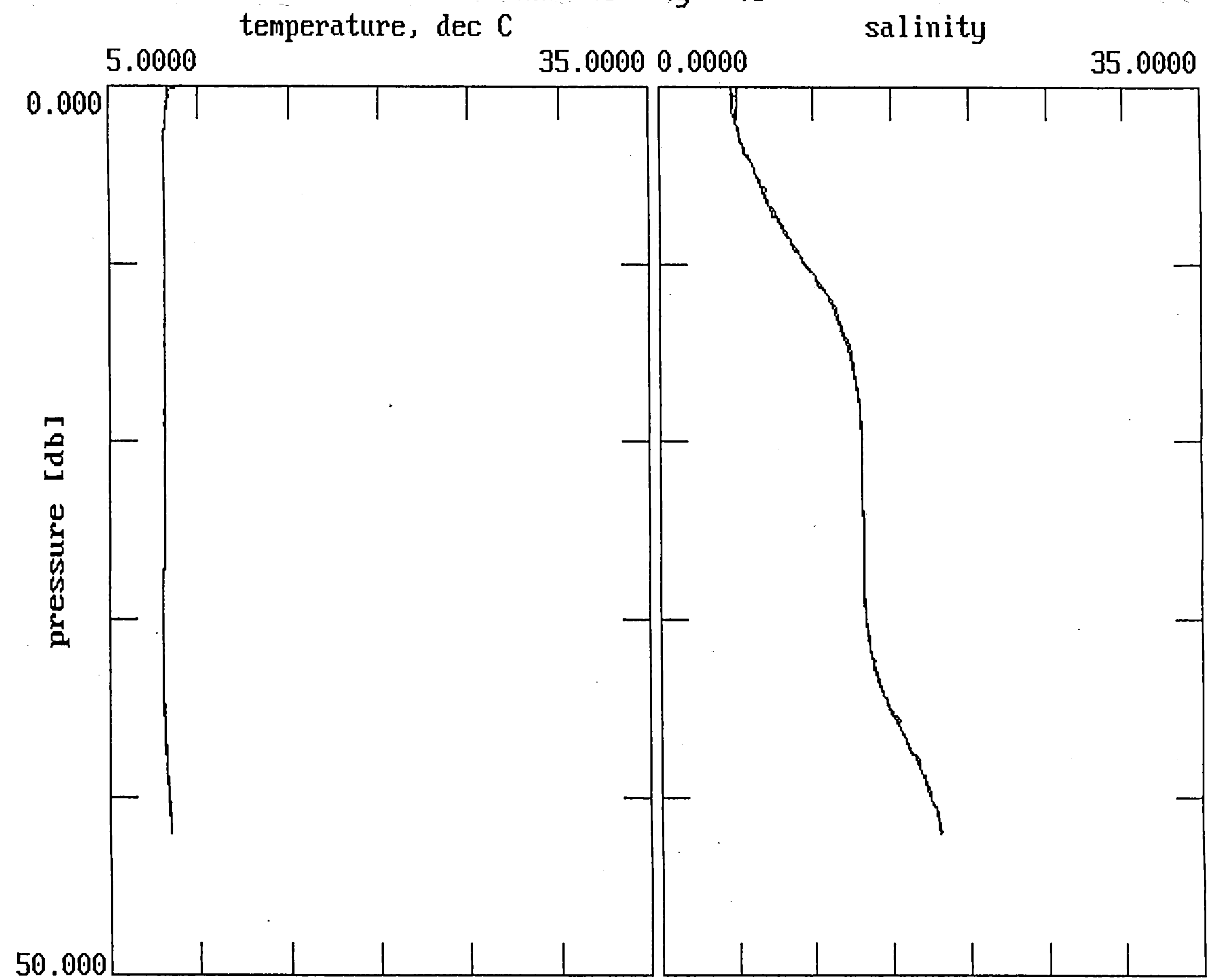
SN = 523 P = -0.089 T068=13.9176 Sal= 0.1175 MAH02438.HEX



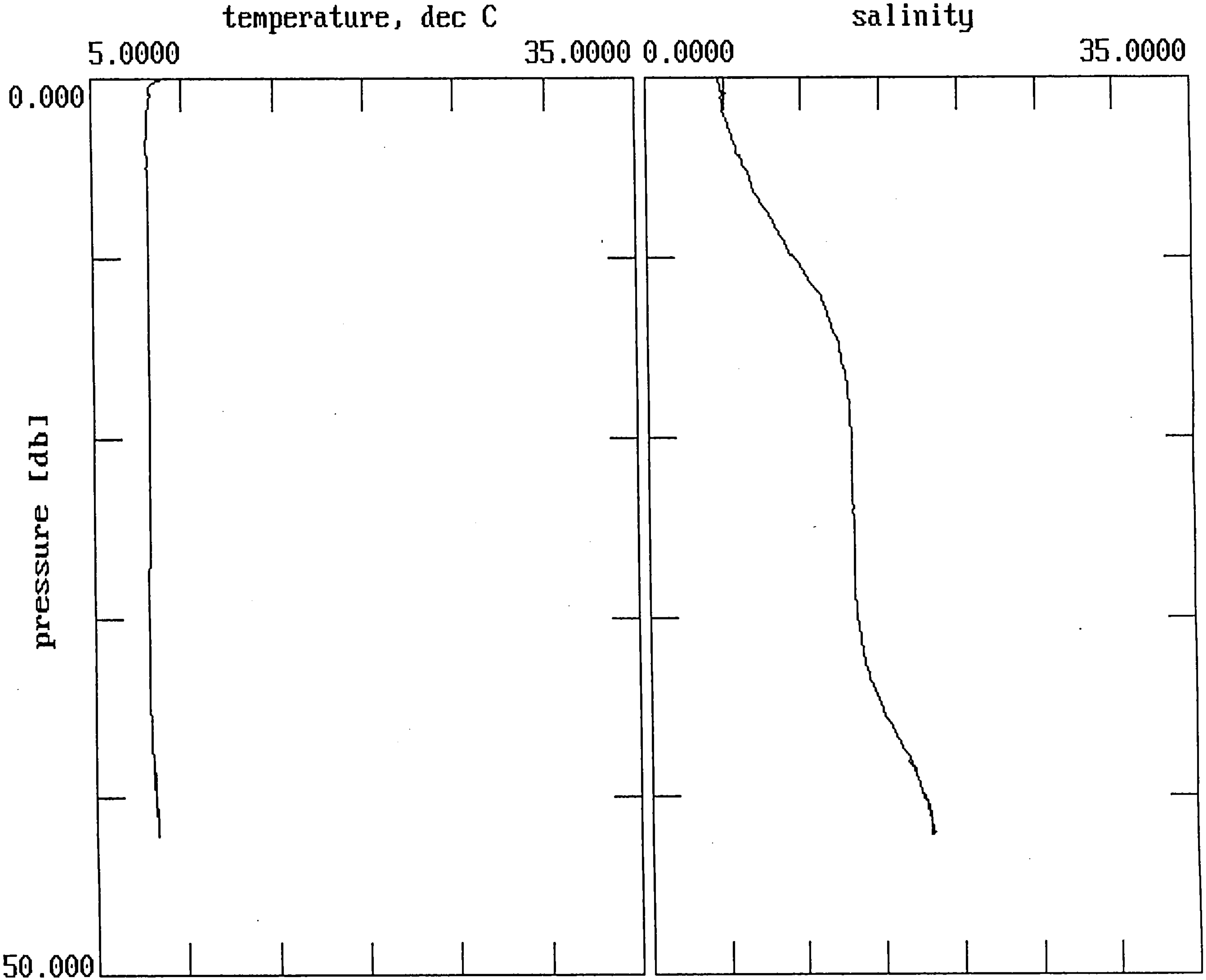
SN = 595 P = -0.116 T068=14.2572 Sal= 0.0748 MAH02443.HEX

6


ak lan 24 ly 35 1305 54
temperature, dec C
5.0000
35.0000
salinity
0.0000
35.0000
0.000
pressure [db]
50.000

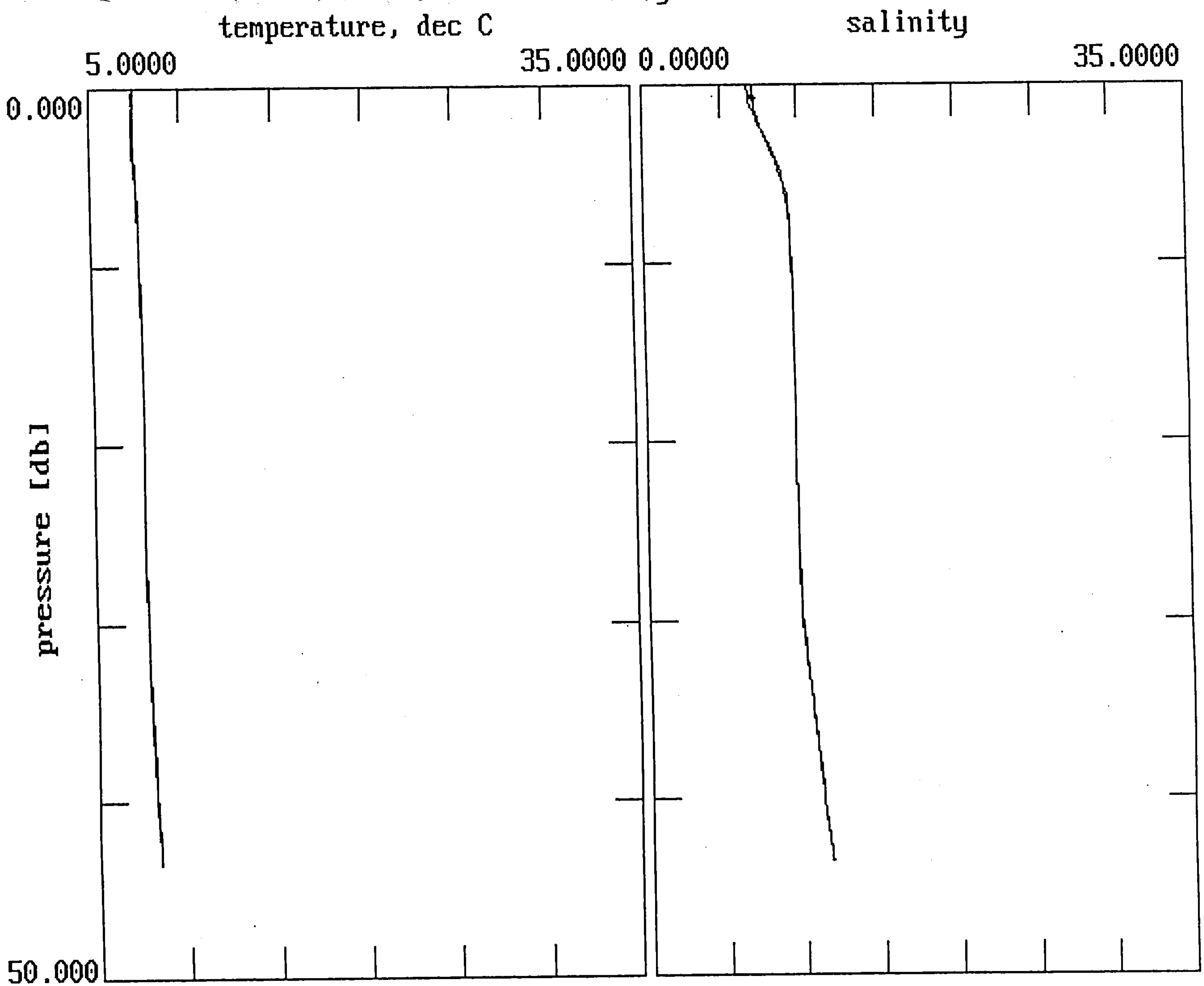


SN = 577 P = -0.116 T068=13.3478 Sal= 0.0730



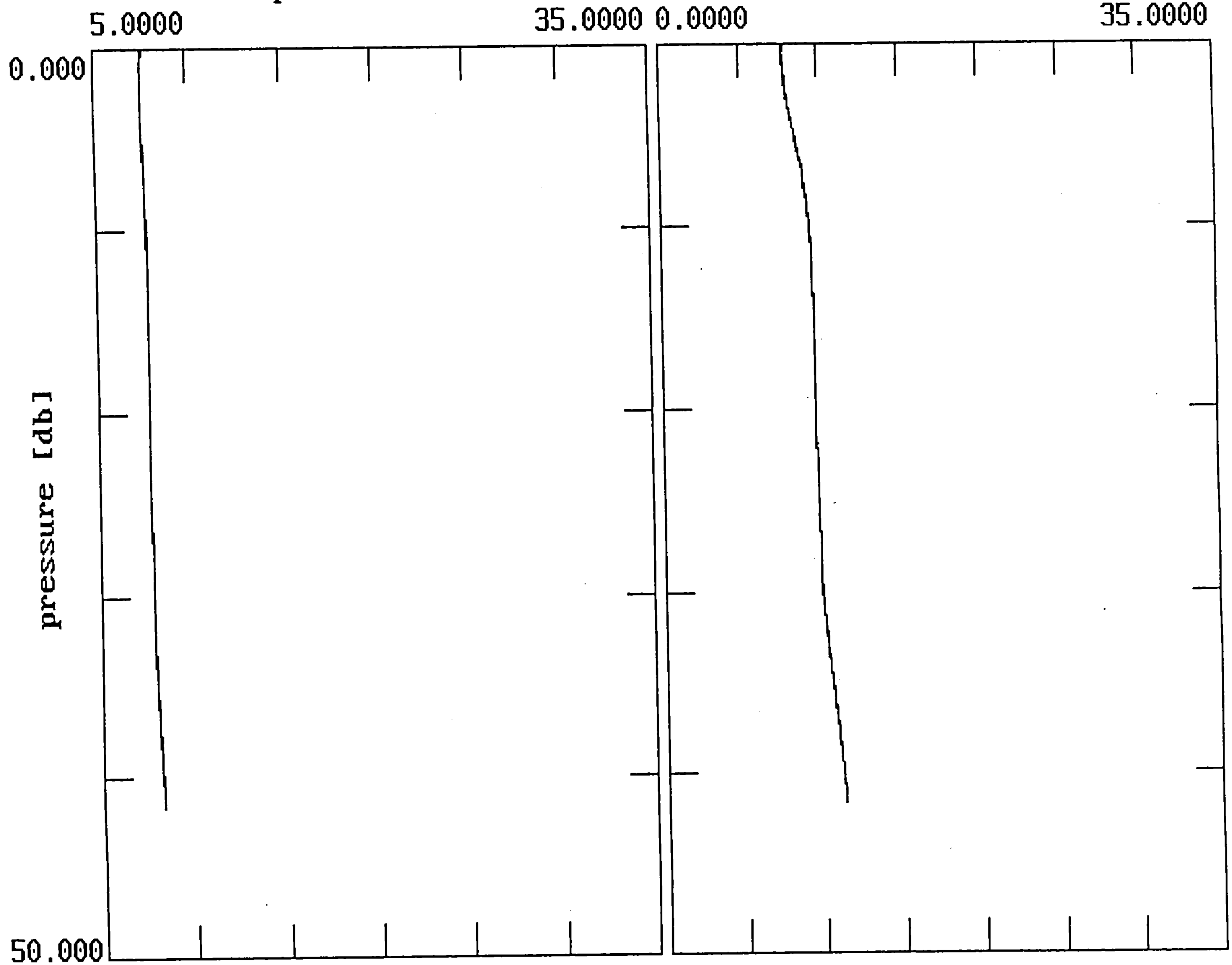
SN = 354 P = 38.179 T068=8.2239 Sal= 16.5524 MAH02458.HEX

9



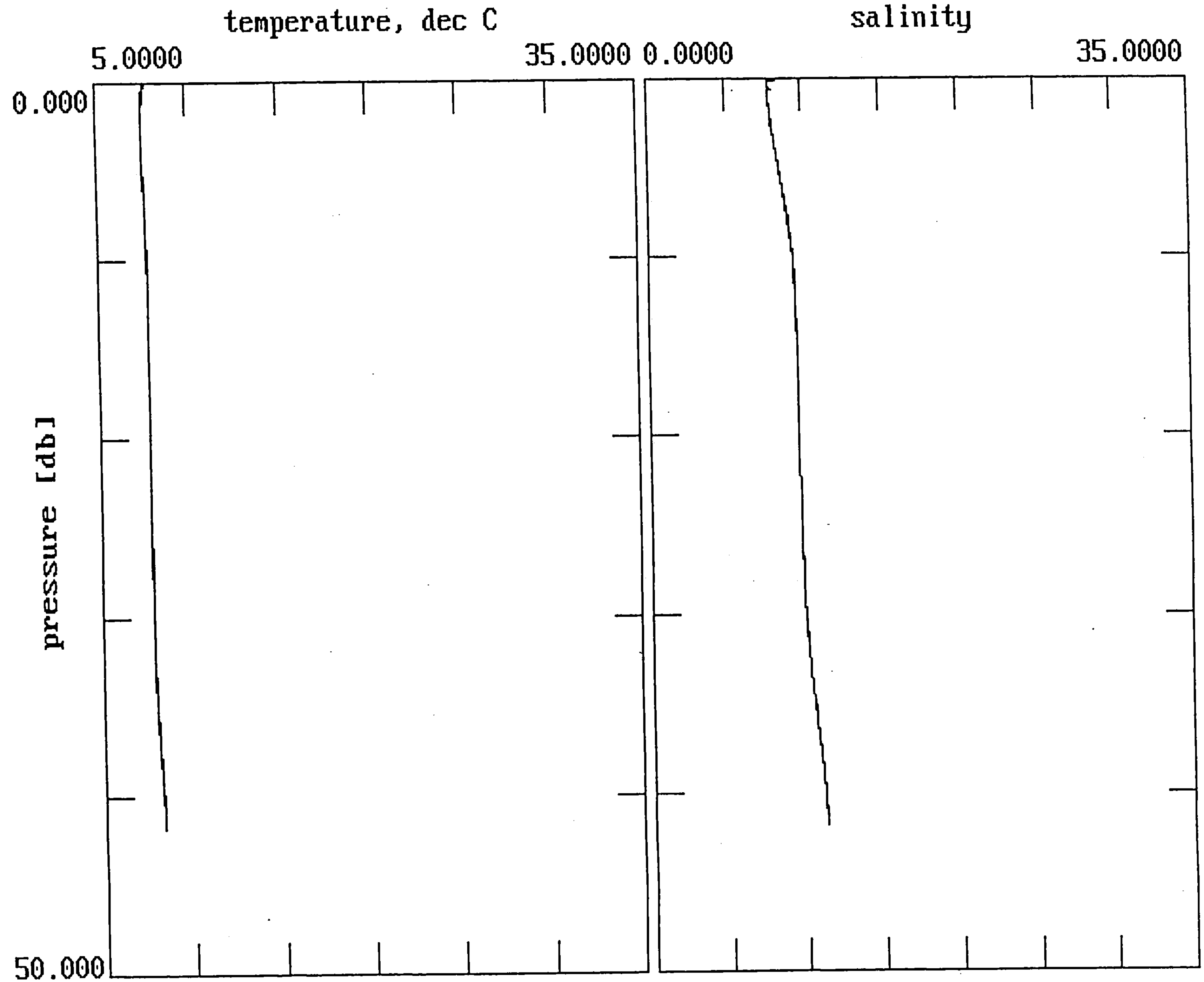
SN = 566 P = -0.169 T068=15.9627 Sal= 0.2718 MAHO2414 HEX

12



SN = 505 P = -0.437 T068=14.2526 Sal= 0.1360 MAH02439.HEX

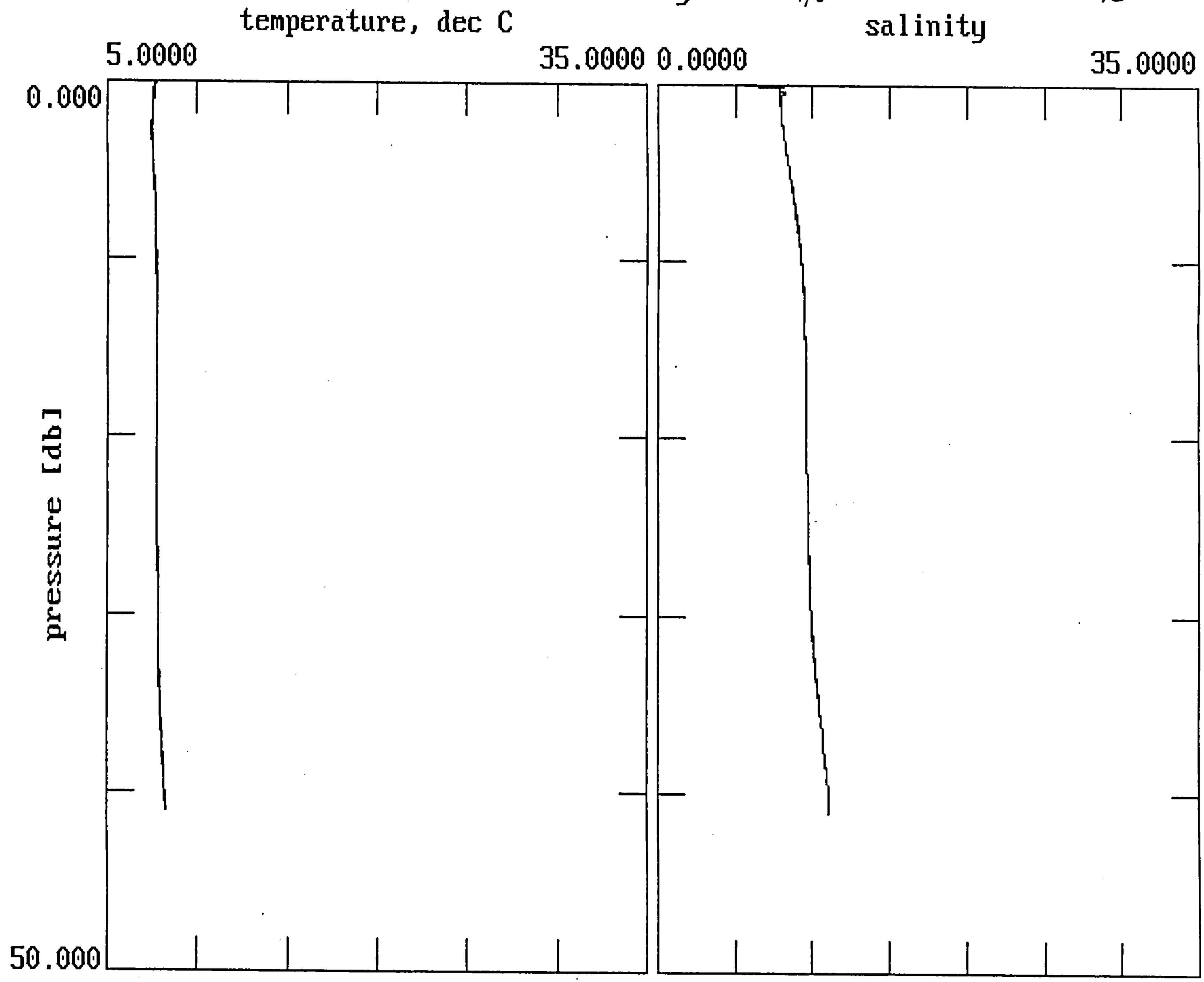
13



SN = 546 P = -0.089 T068=18.9239 Sal= 0.1248 MAH02444.HEX

k lan 24 y 35 .8 17 20 7.55.10

14



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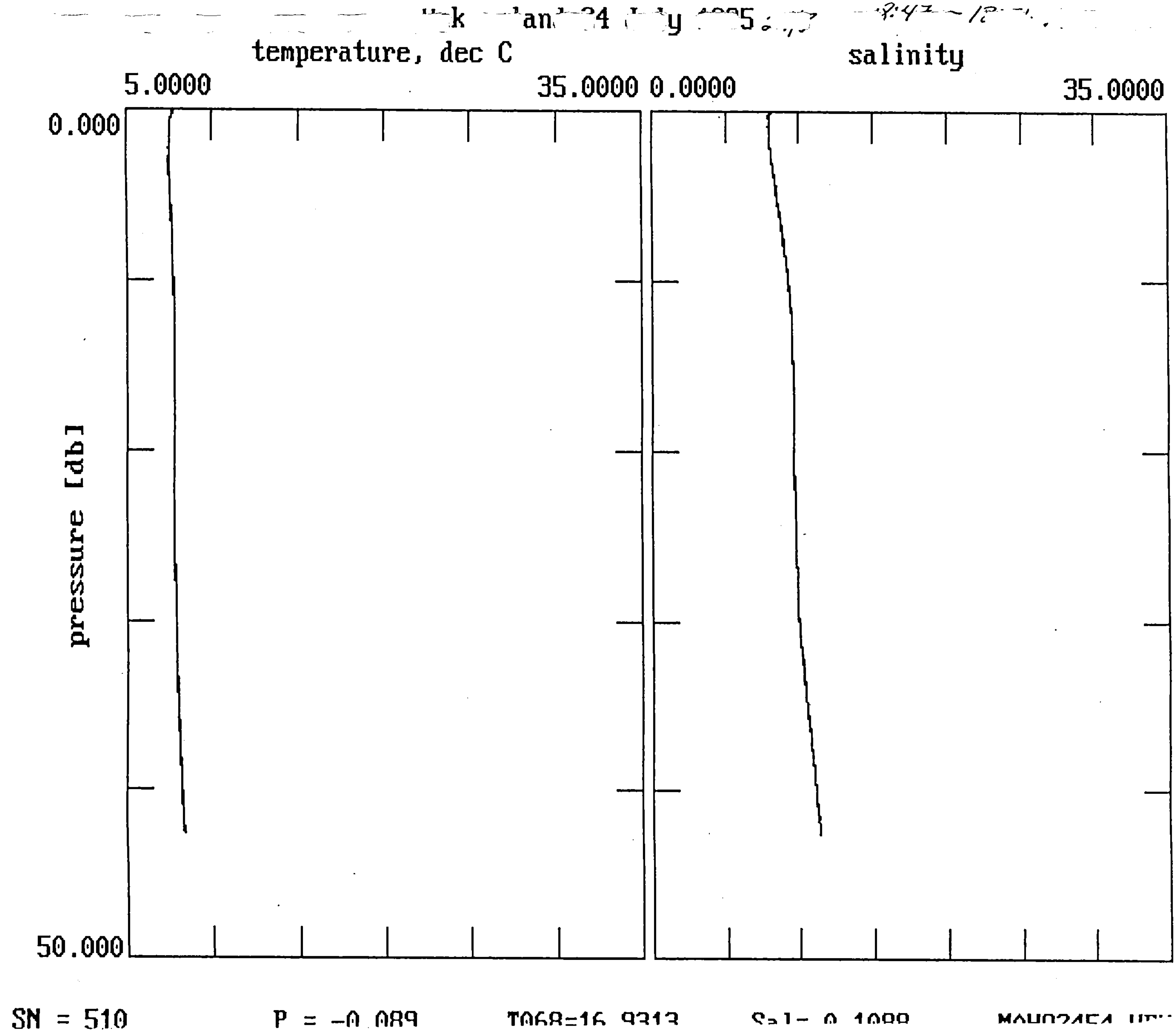
15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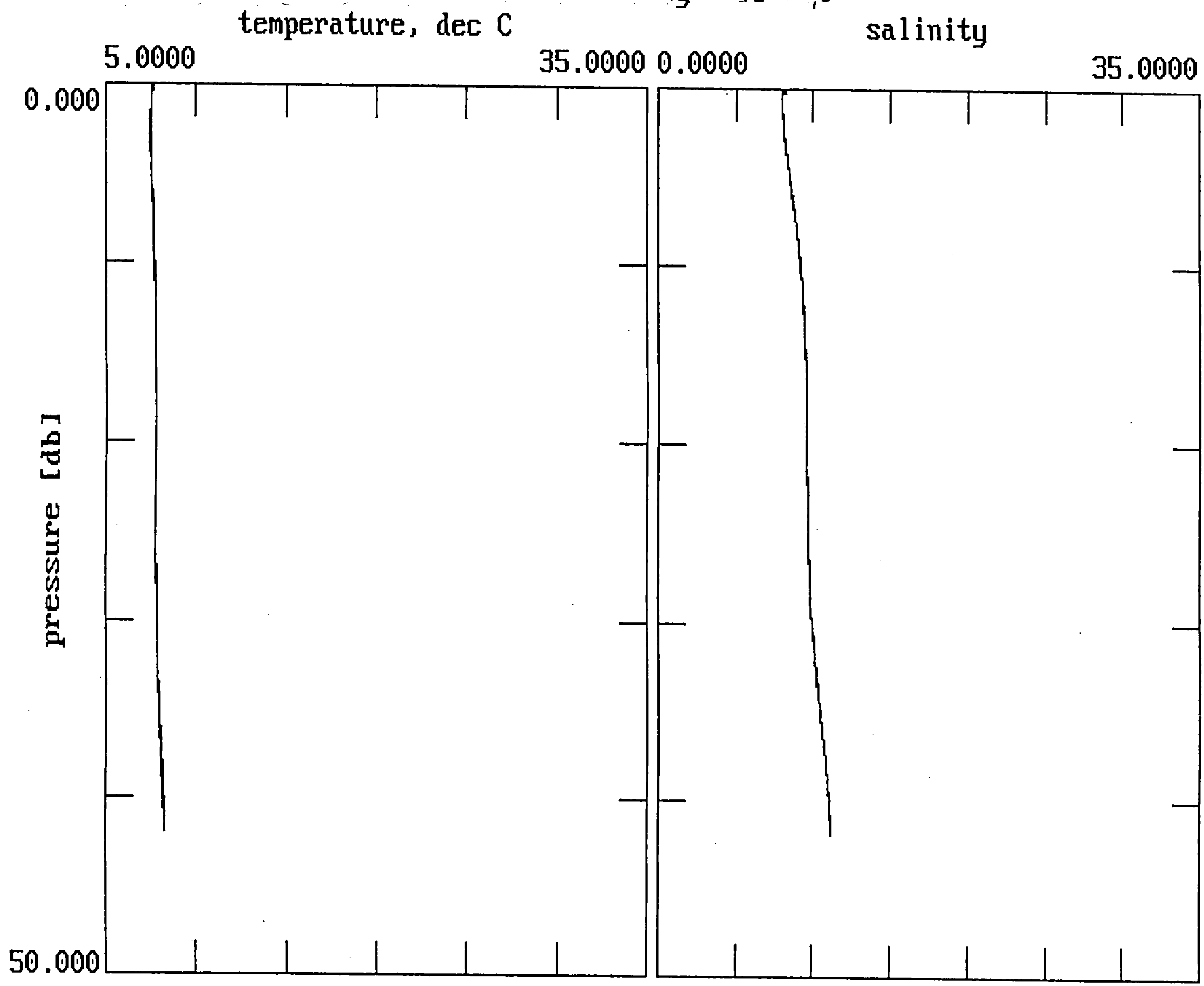
T068=16.9313

k lan 24 y 95 8 48



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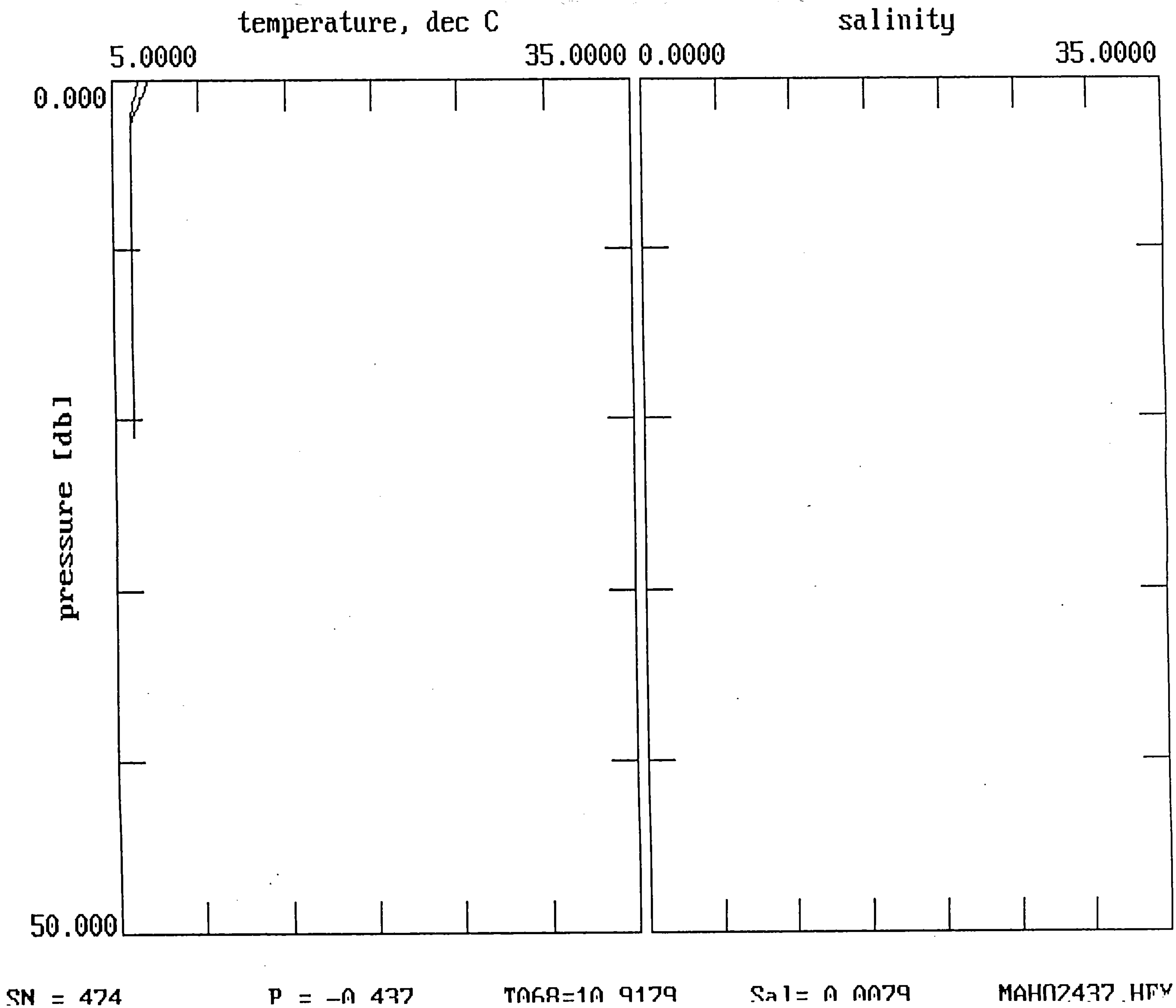

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pressure [db]
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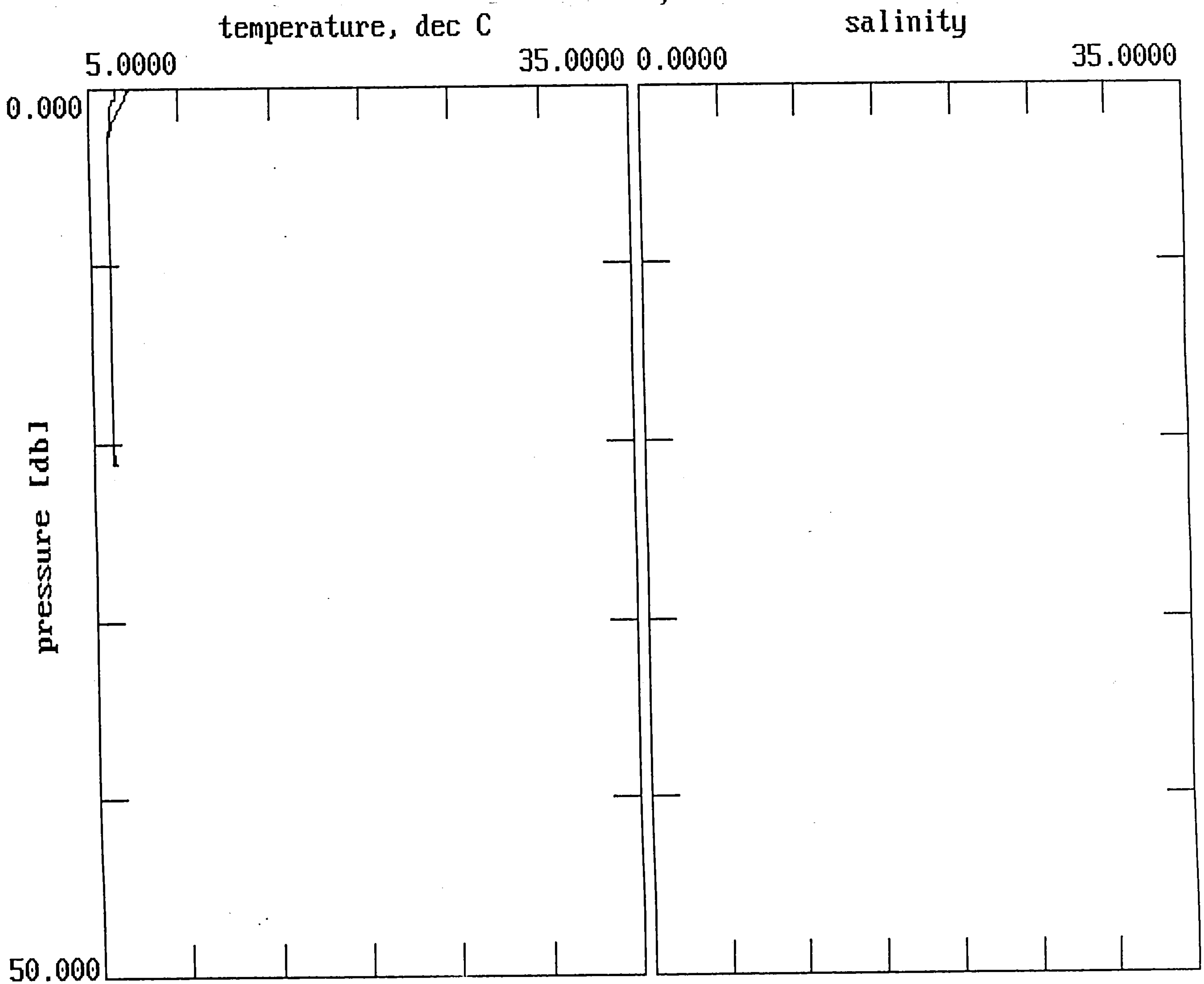
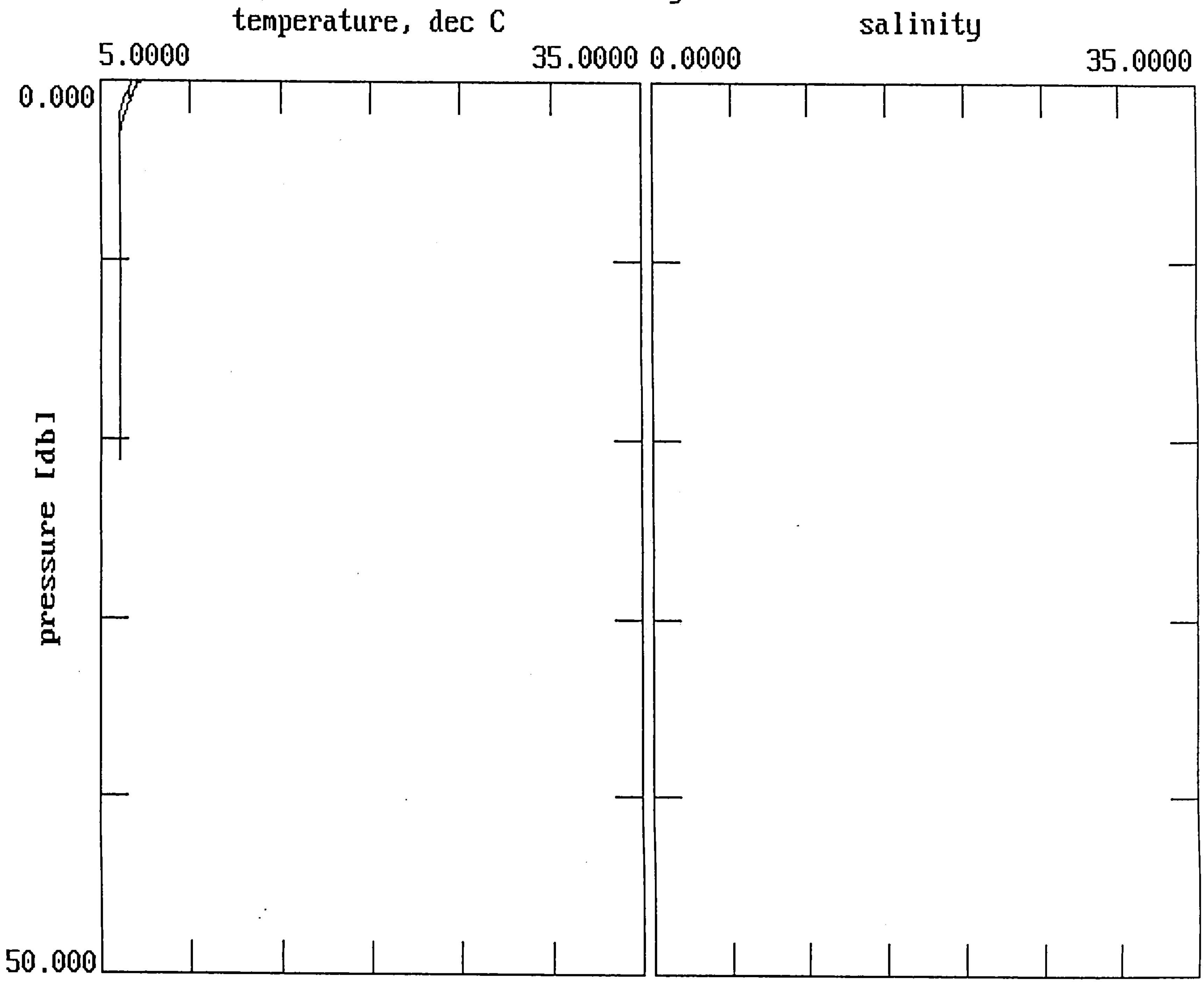
P = -0.437
T068=10.9179
Sal= 0.0079
MAH02437.HEX

18

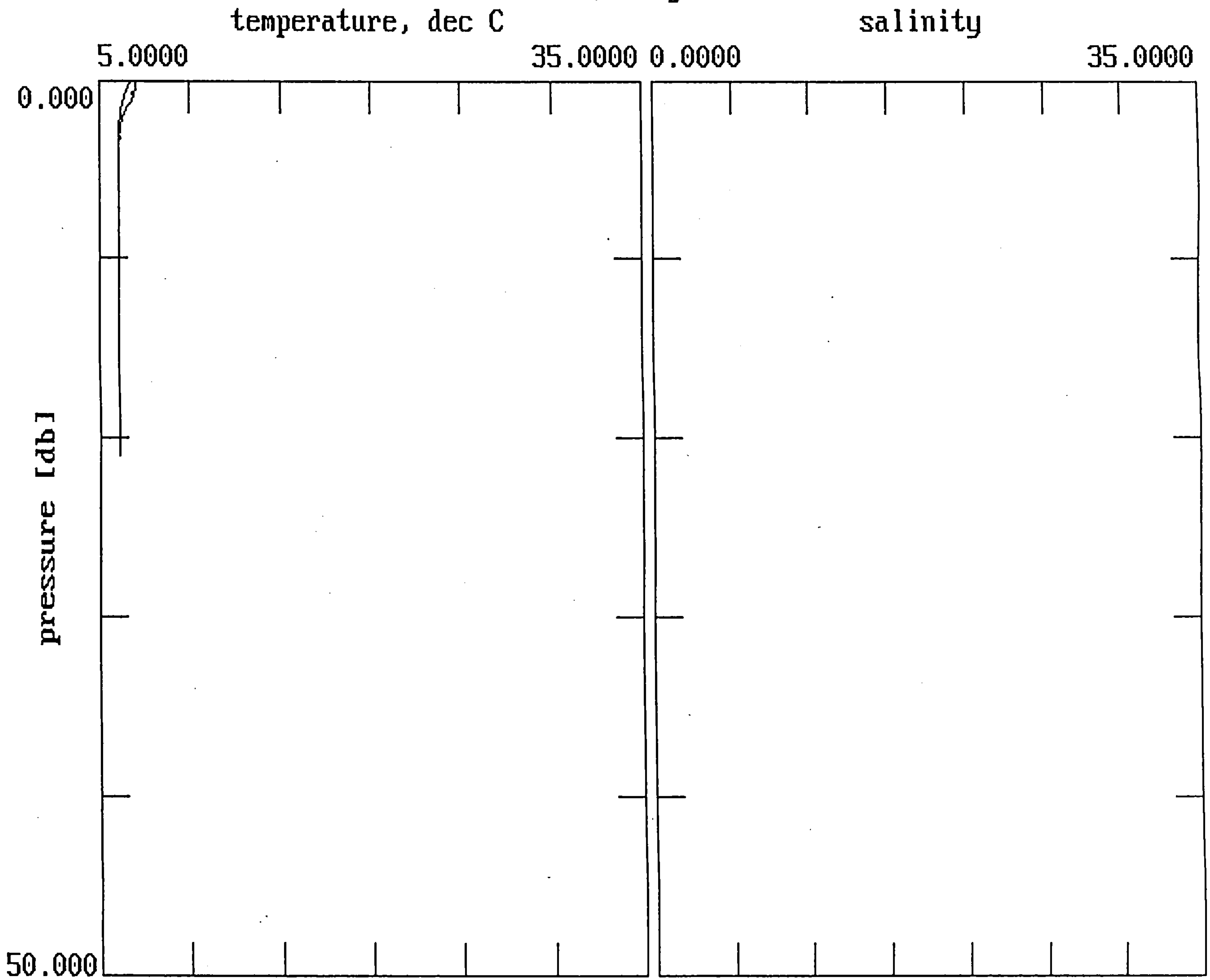


SN = 546 P = -0.089 T068=14.8623 Sal= 0.0110 MAHO2442.HEX

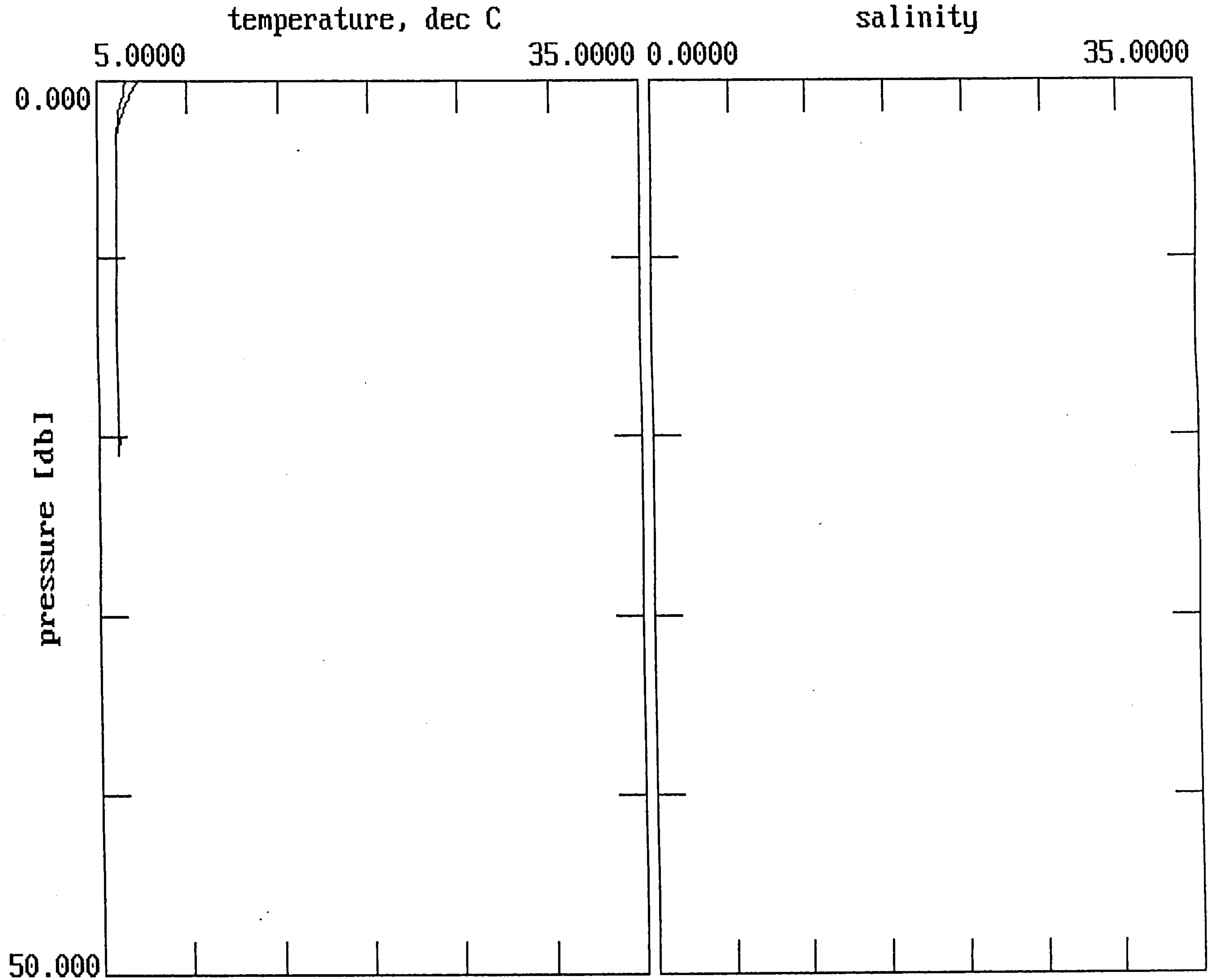
19



SN = 392 P = -0.142

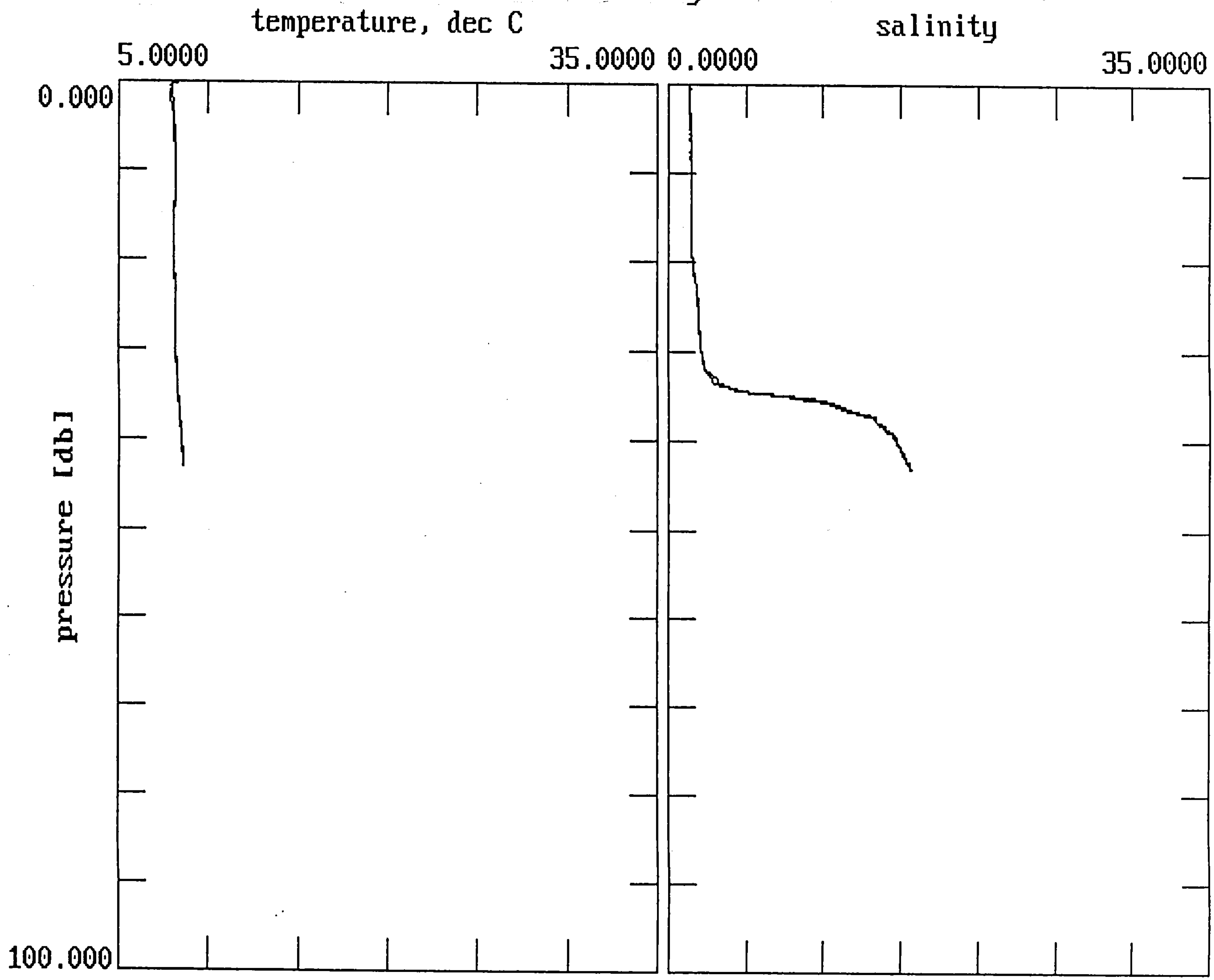


SN = 520 P = -0.142 T068=15.5886 Sal= 0.0106 MAH02452 HEX



SN = 391 P = -0.116 T068=12.4542 Sal= 0.0088 MAH02457 HEX

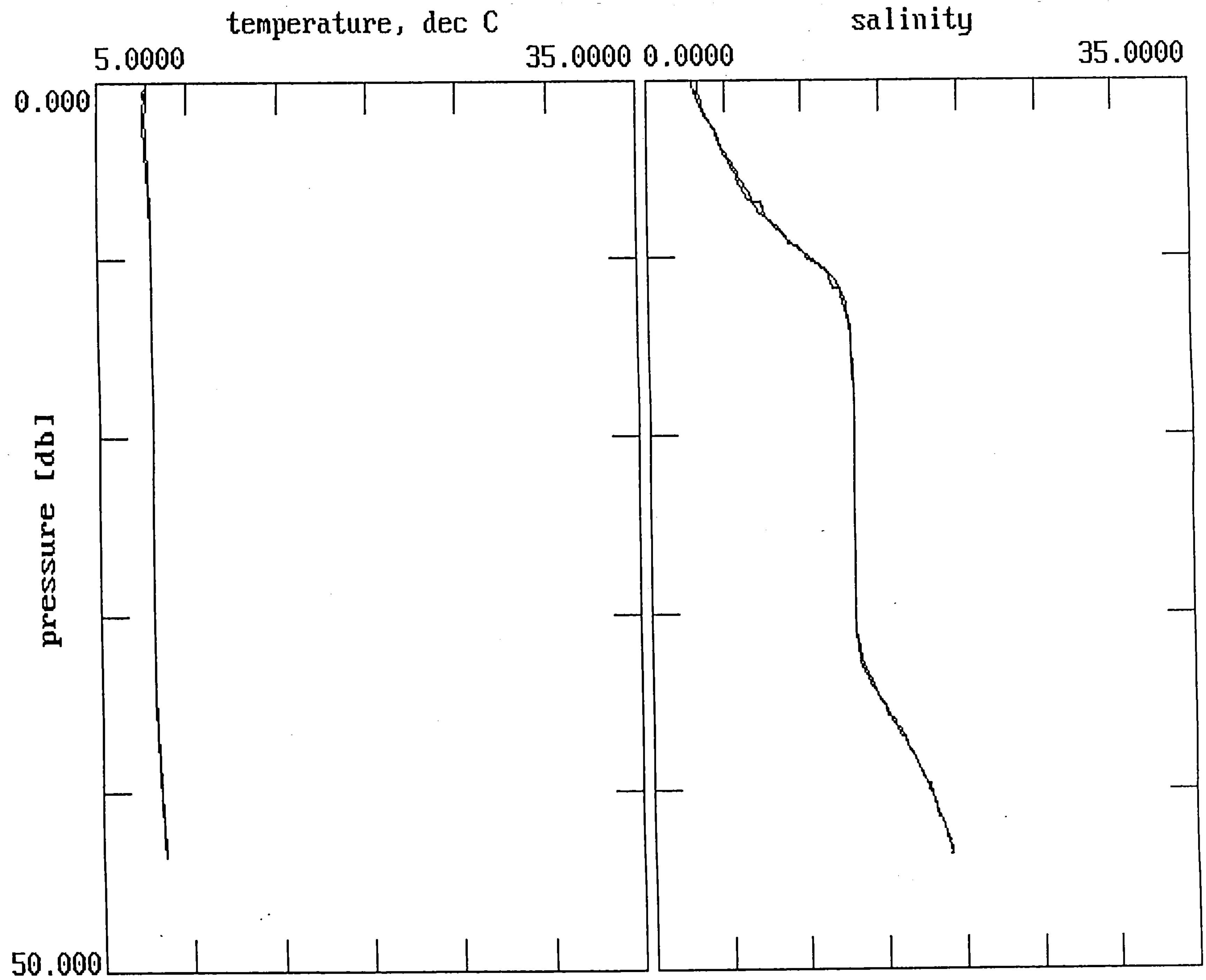
22



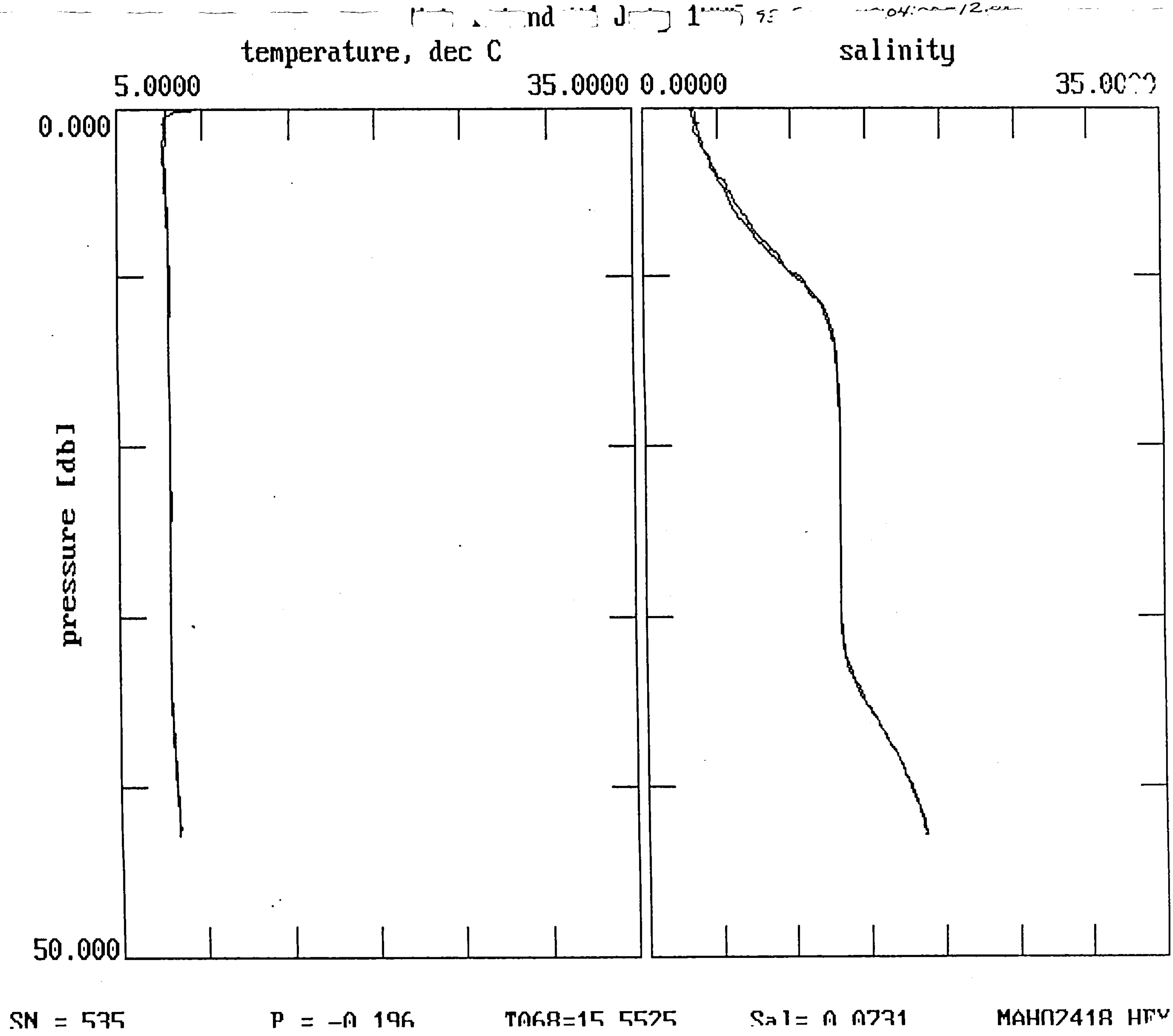
SN = 558 P = -0.035

land 24 July 1995 9305 11:00:50 – 11:05:06

23



SN = 499 P = -0.223 T068=14.6743 Sal= 0.1348 MAHO2413.HEX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50.000
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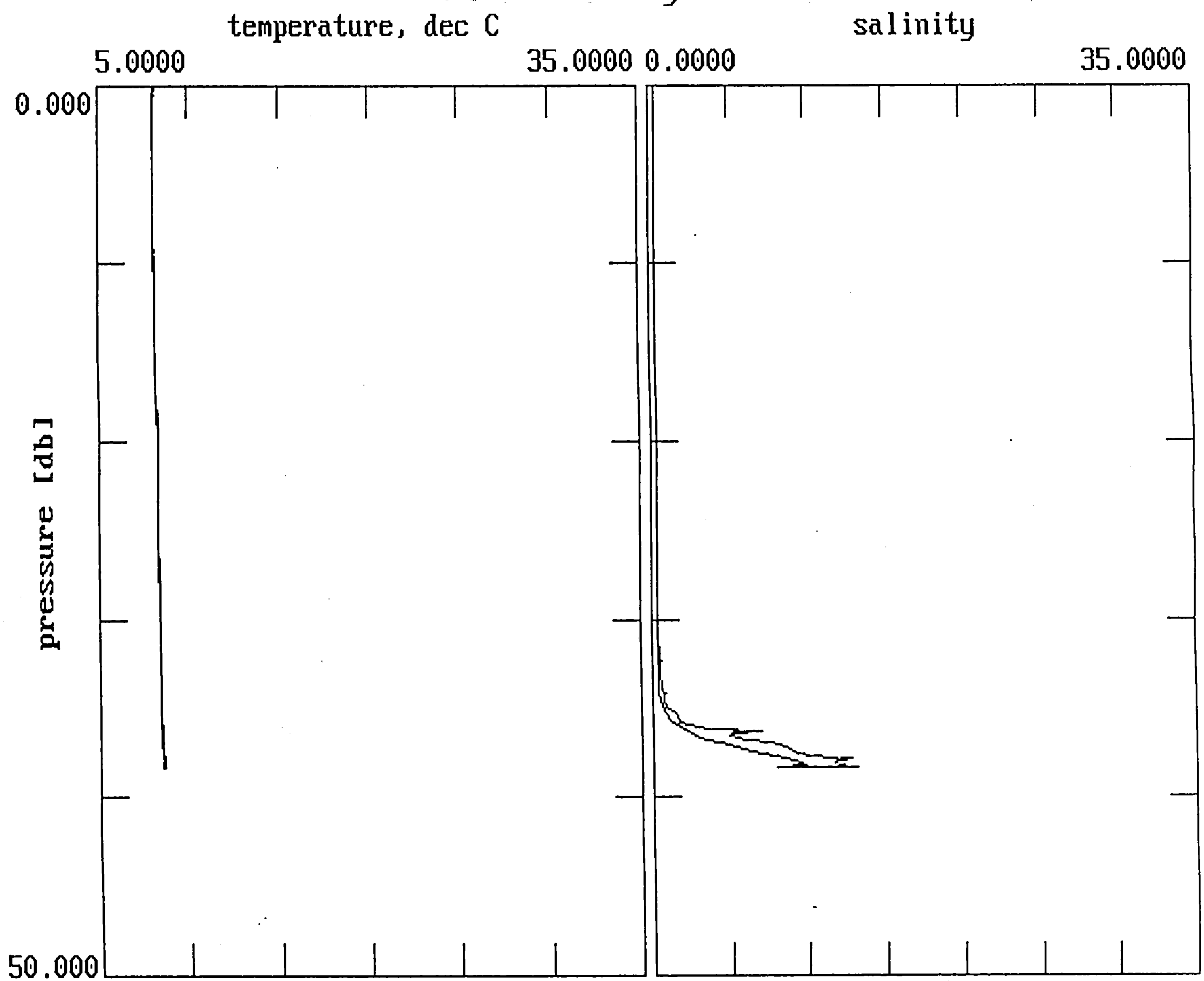
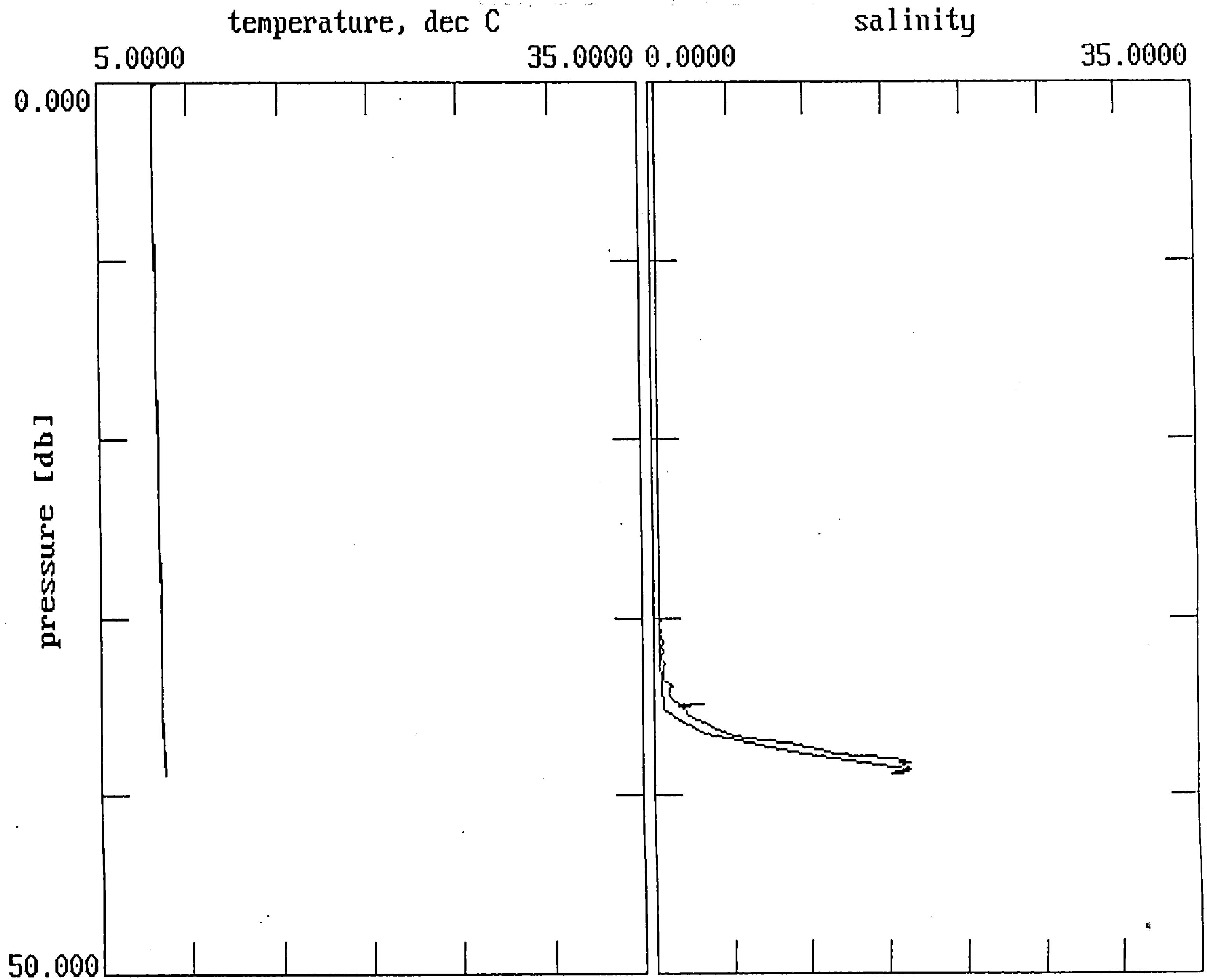
P = -0.196
T068=15.5525
Sal= 0.0731
MAH02418.HEX



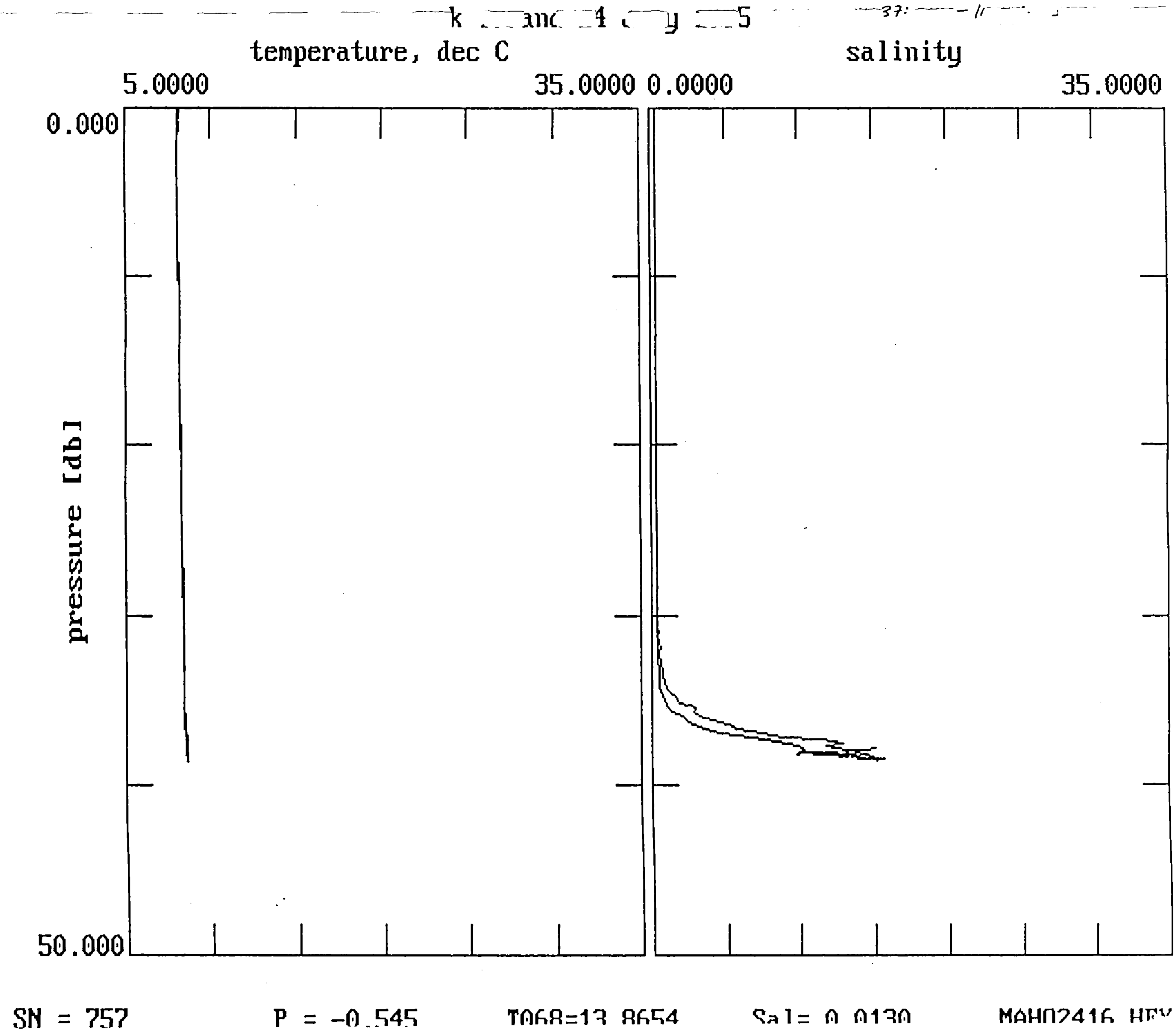
SN = 515 P = -0.196 T068=11.5818 Sal= 0.0146 MAHO2408.HEX

Hak . Land 24 July 1995 A 10:36:50 - 10:41:31

26



SN = 549 P = -0.169 T068=12.9583 Sal= 0.0217 MAHO2411.HEX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salinity
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35.0000
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50.000
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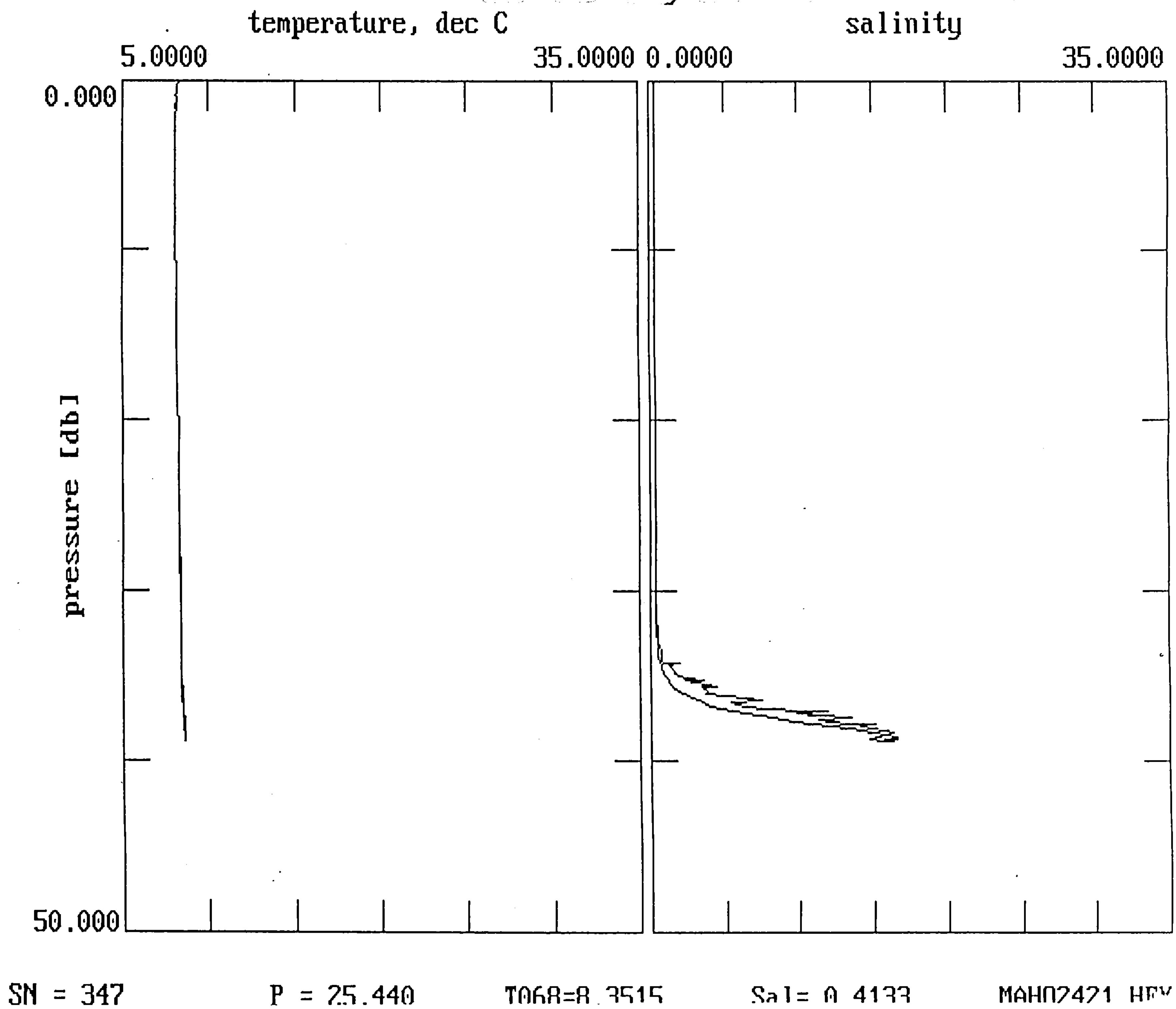
T068=13.8654
Sal= 0.0130
MAH02416.HEX

28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P = 25.440
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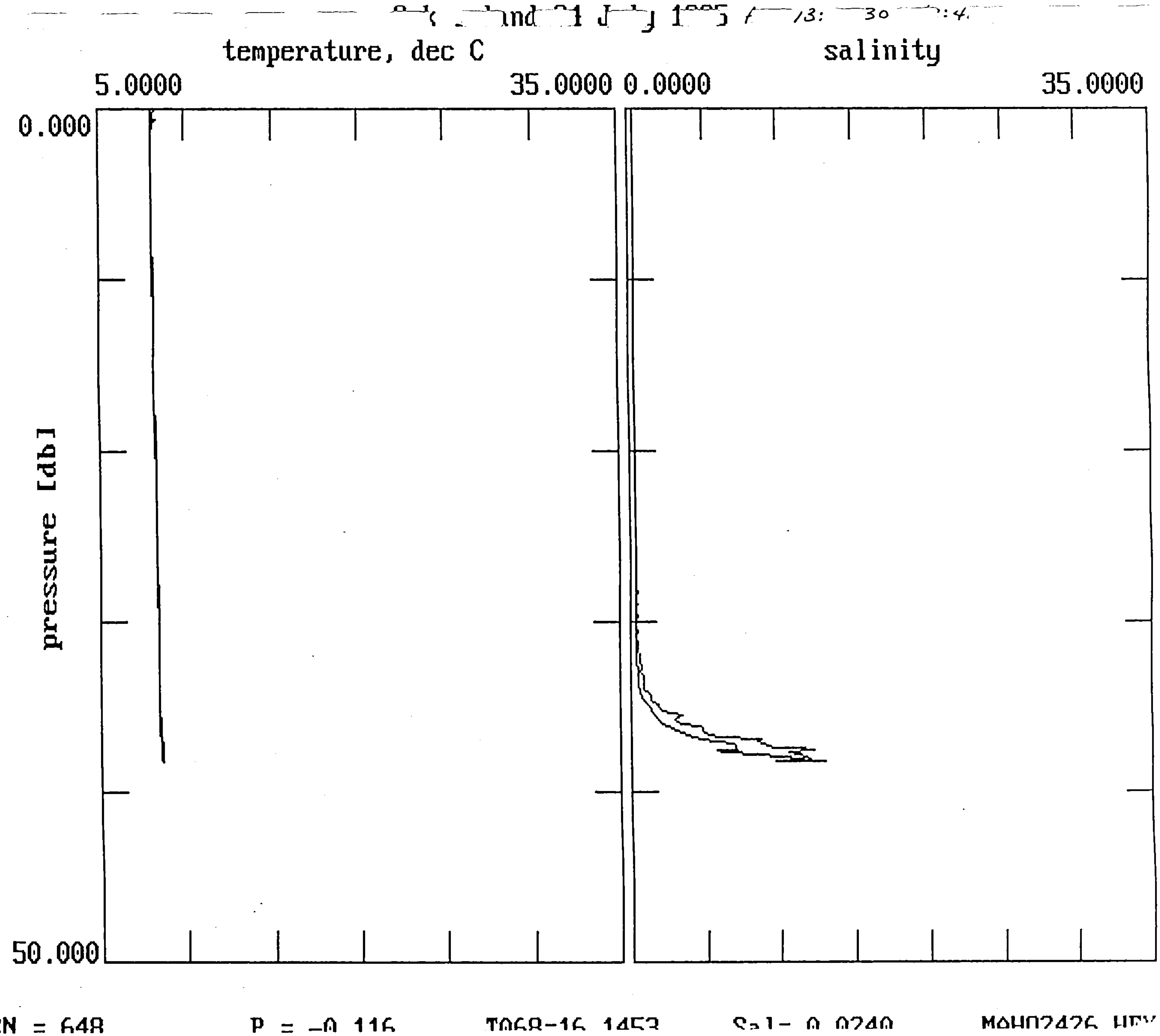
Sal= 0.4133
MAH02421 HEX


temperature, dec C
salinity
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pressure [db]
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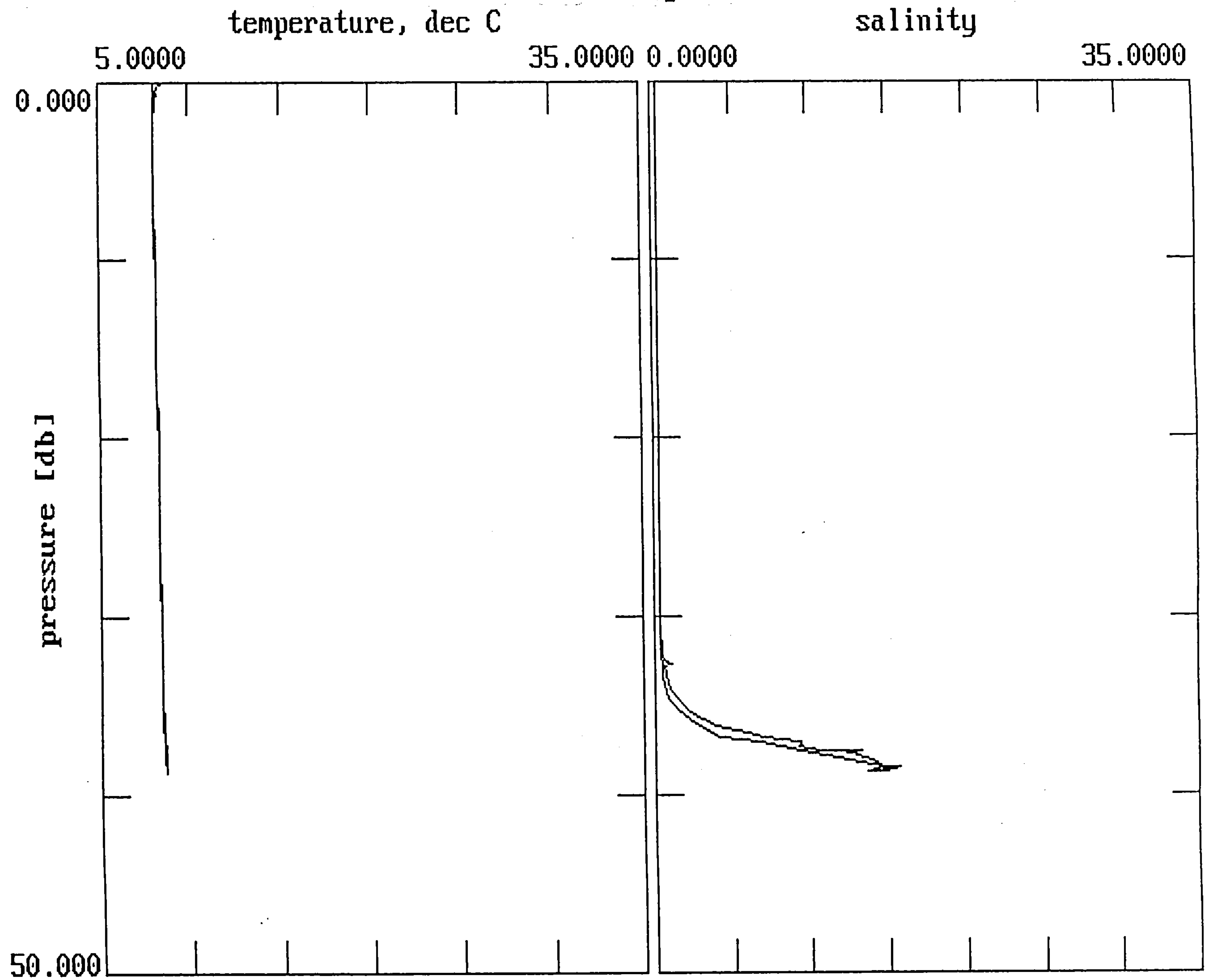
T068-16.1453
Sal- 0.0240
MAH02426 HEX

30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35.0000
salinity
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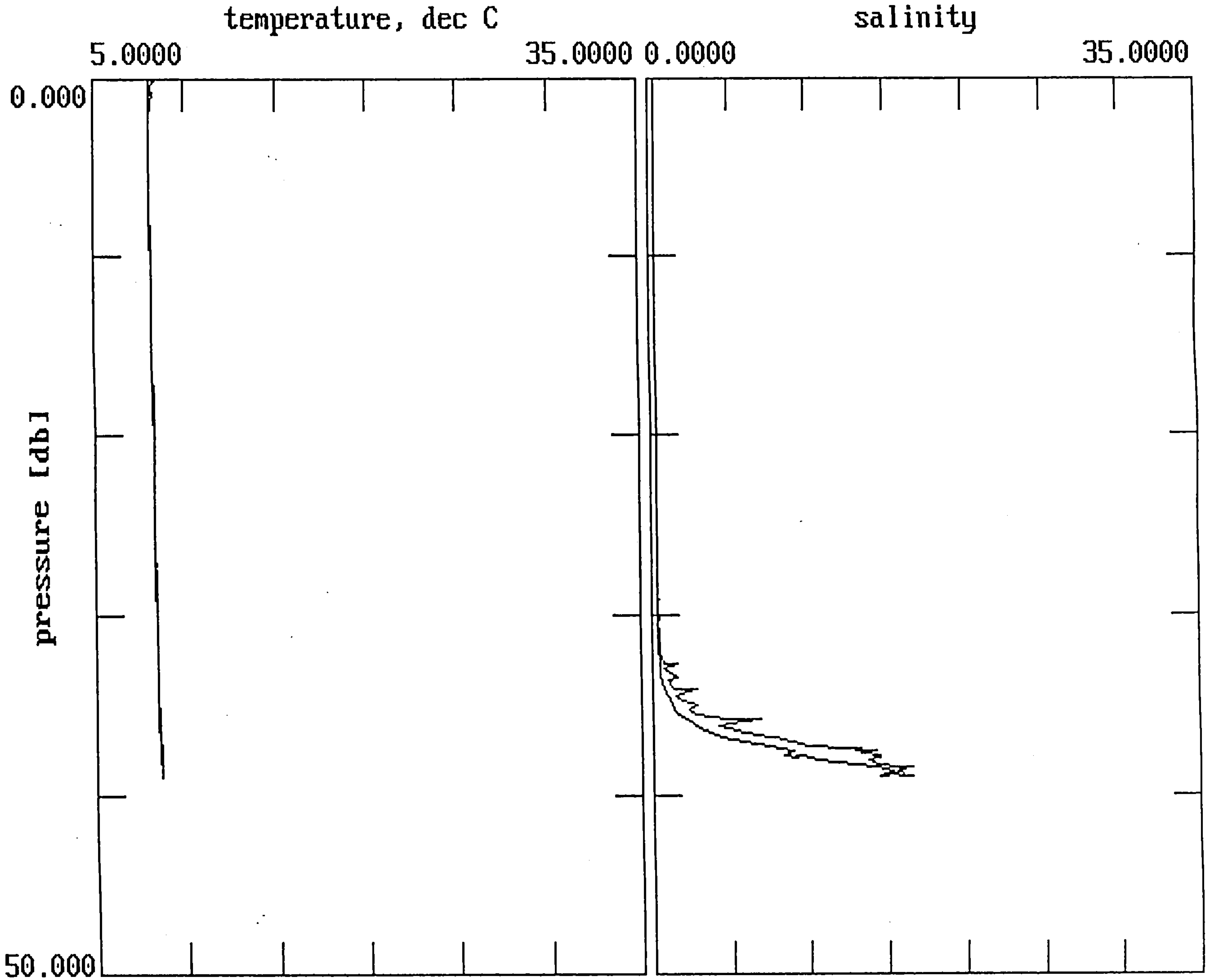
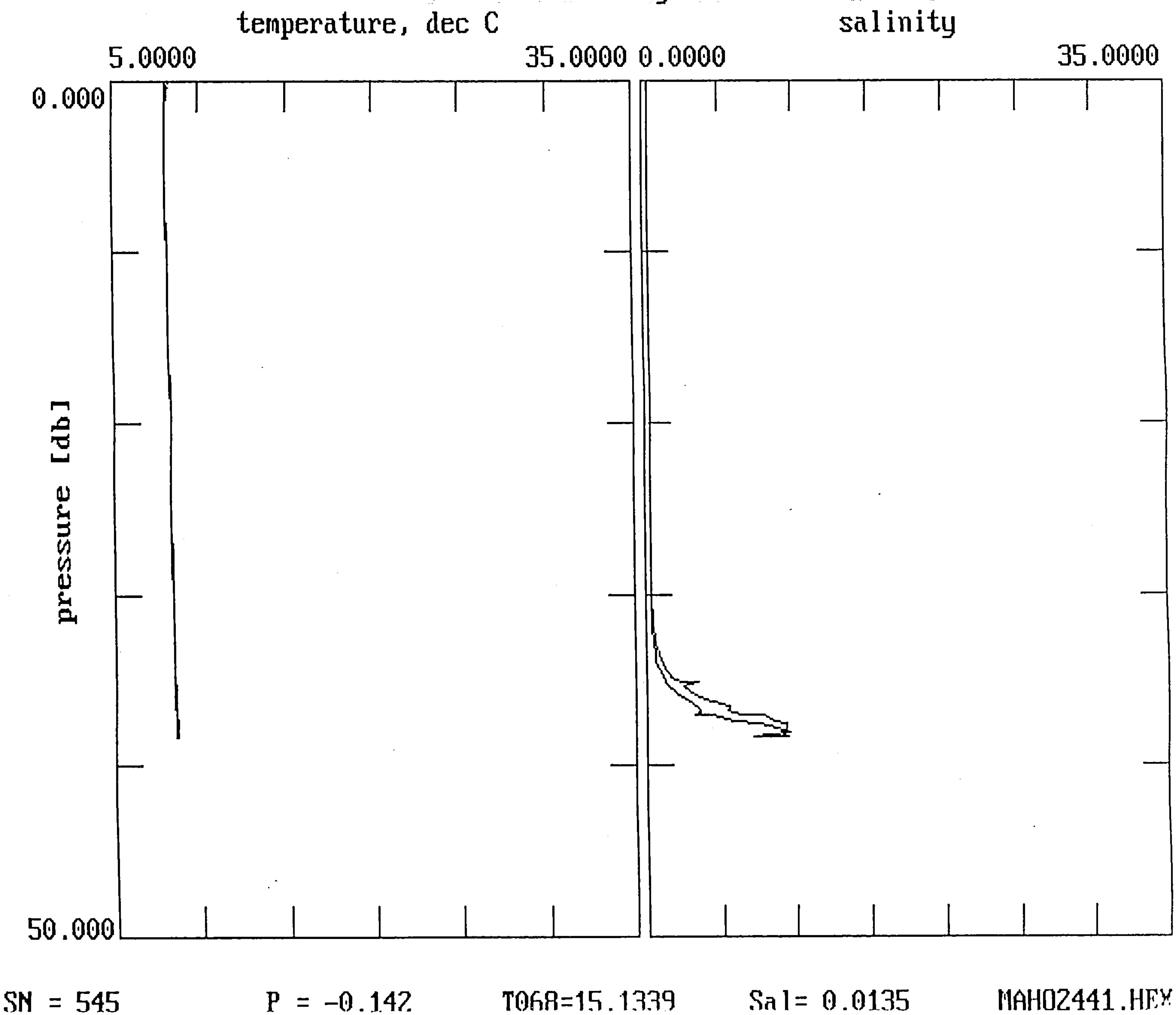
35.0000
0.000
50.000
pressure [db]



SN = 608 P = -0.169 T068=14.6020 Sal= 0.0133 MAHO2436.HEX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salinity
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pressure [db]
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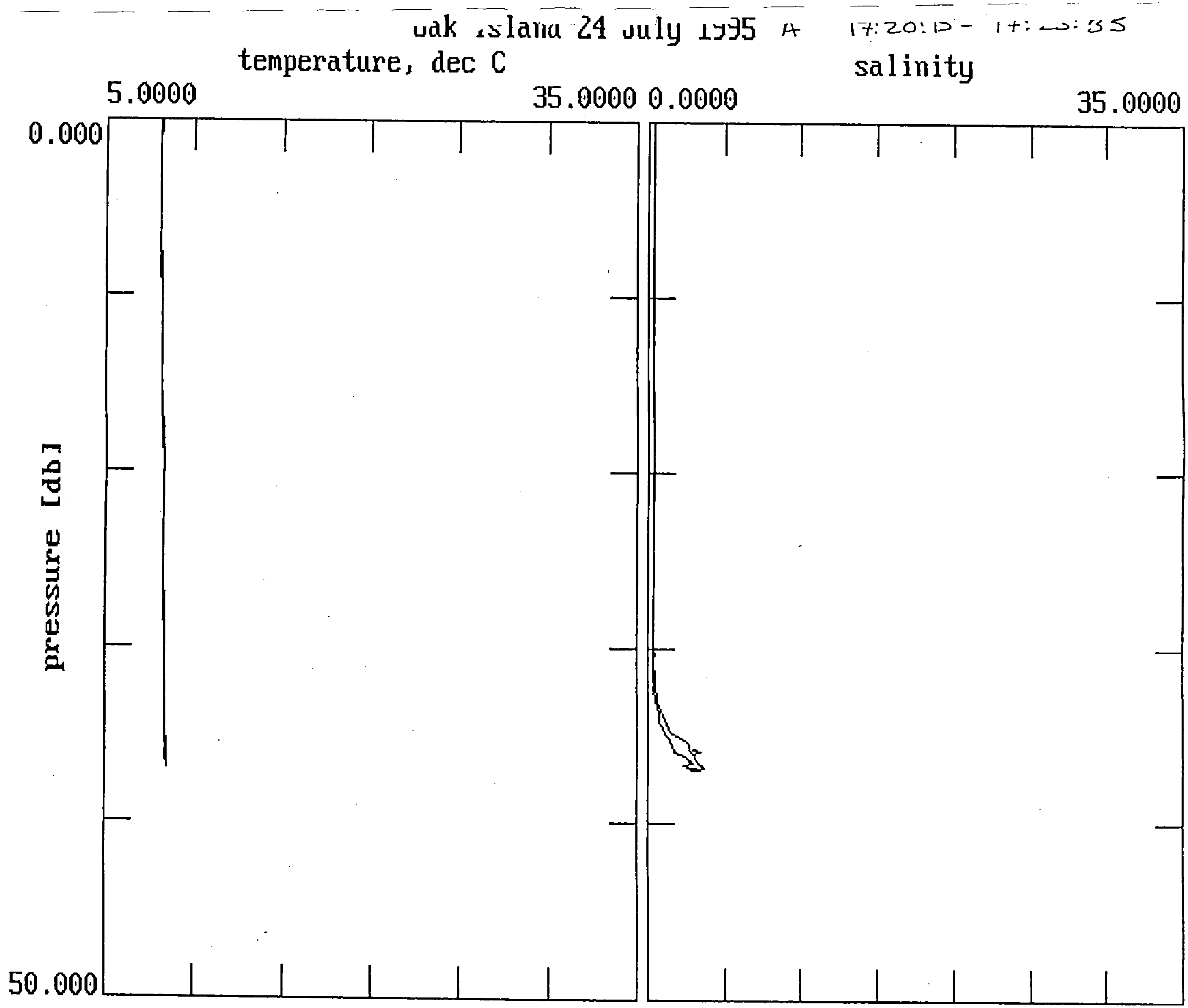
SN = 545
P = -0.142
T068=15.1339
Sal= 0.0135
MAHO2441.HEX

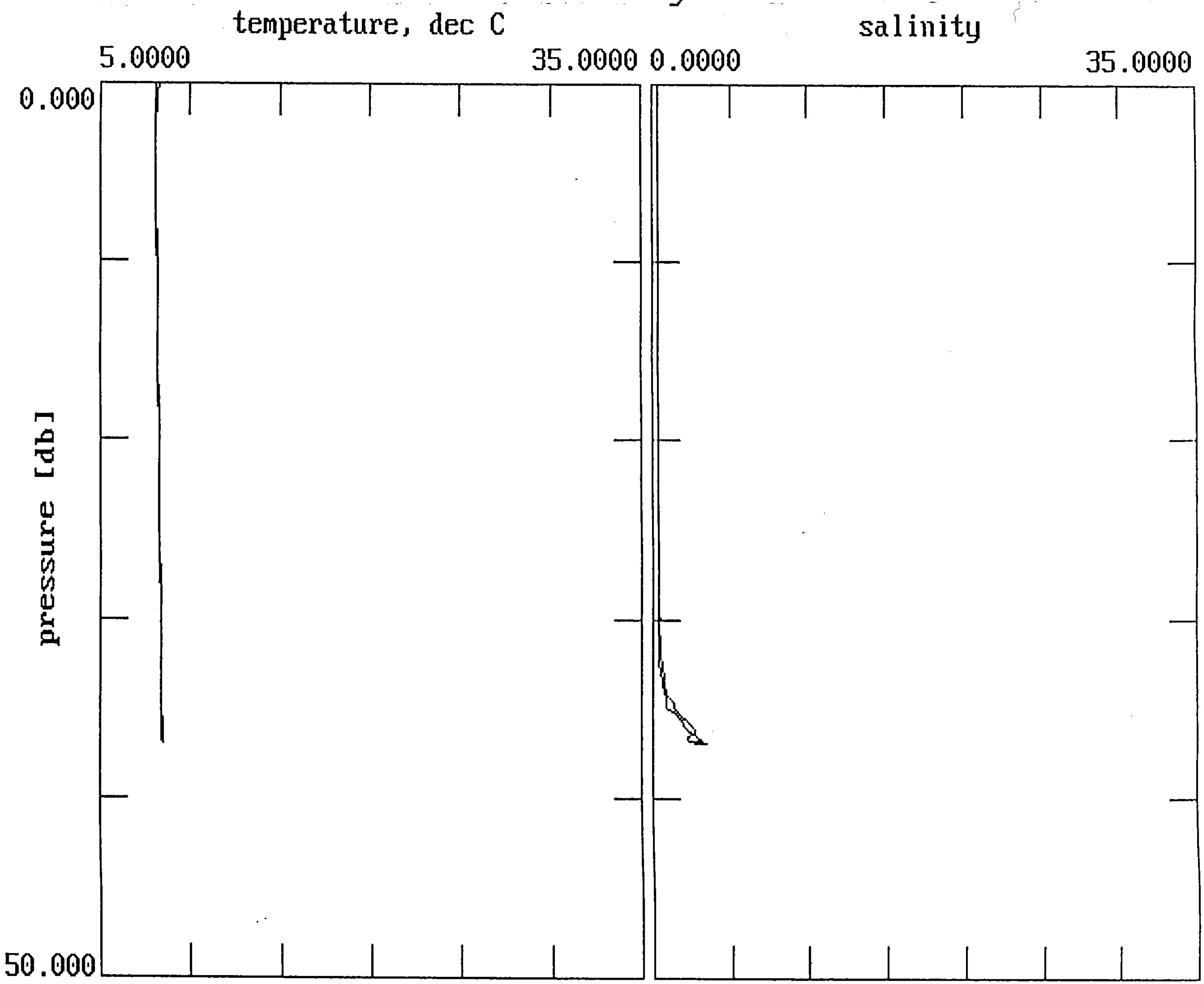
33



oak island 24 july 1995 A 17:20:15 - 17:35:35
temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
pressure [db]
50.000

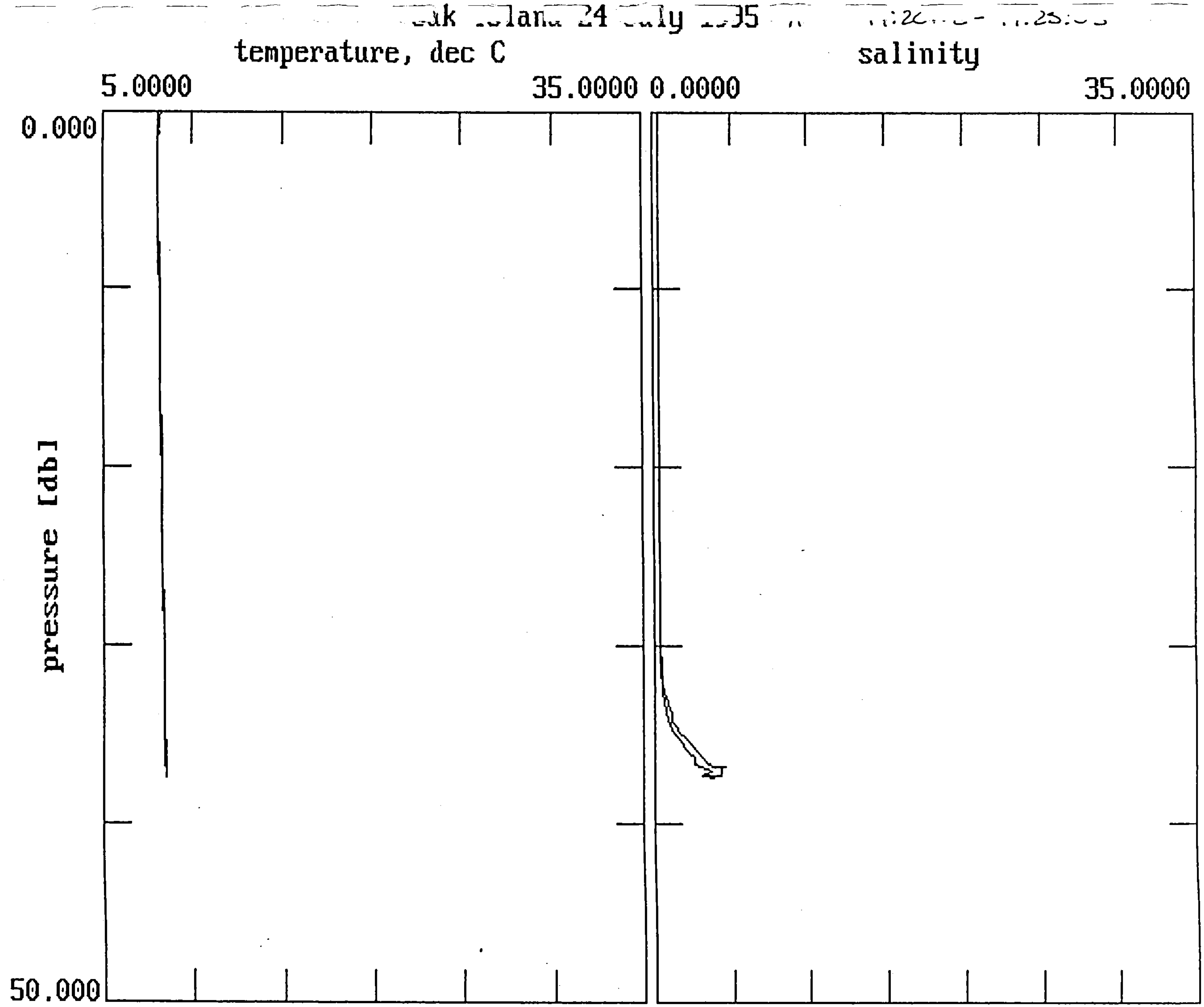
SN = 626

34

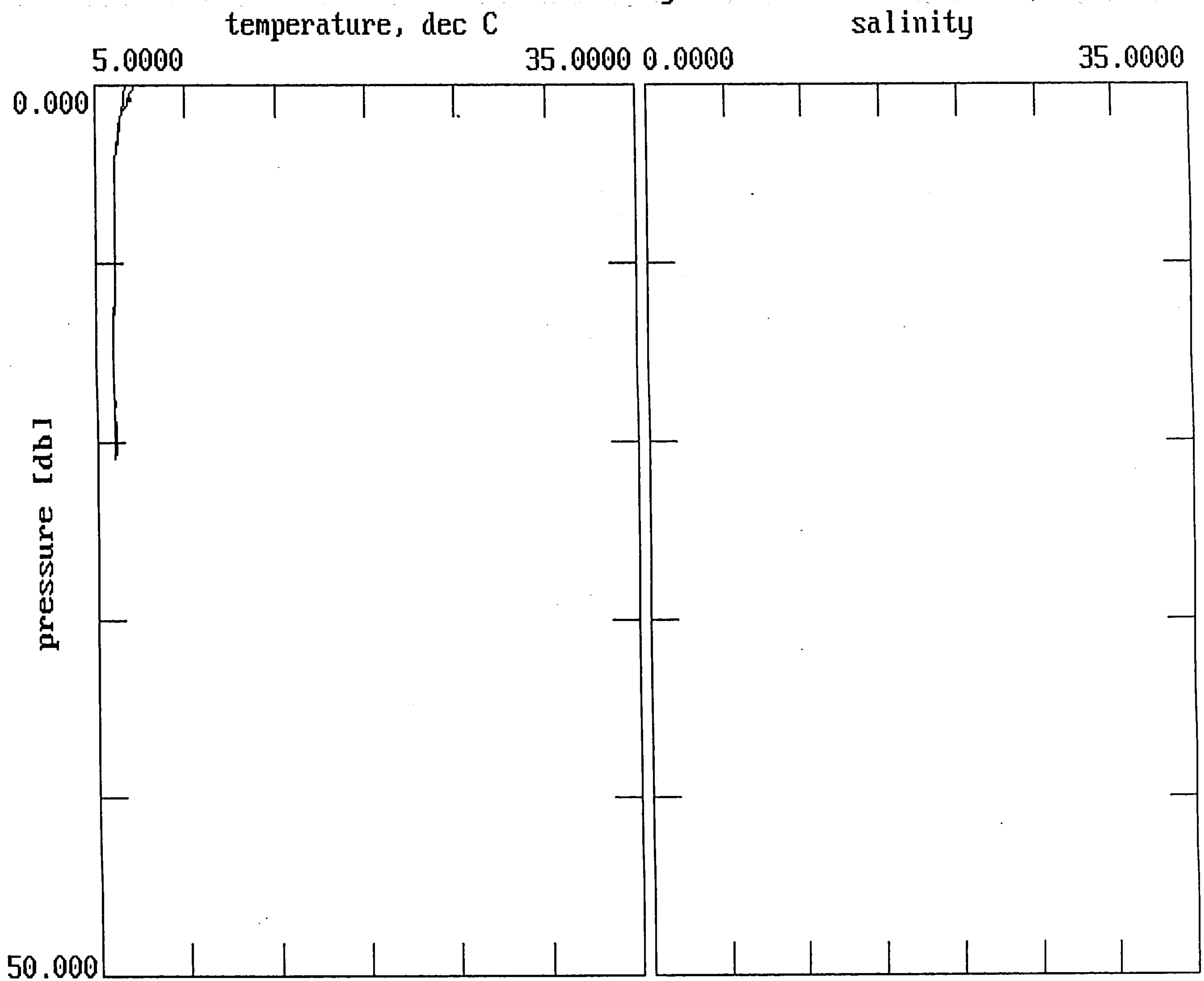


SN = 450 P = -0.089 T068=11.6278 Sal= 0.0147 MAH02451 HEX

35

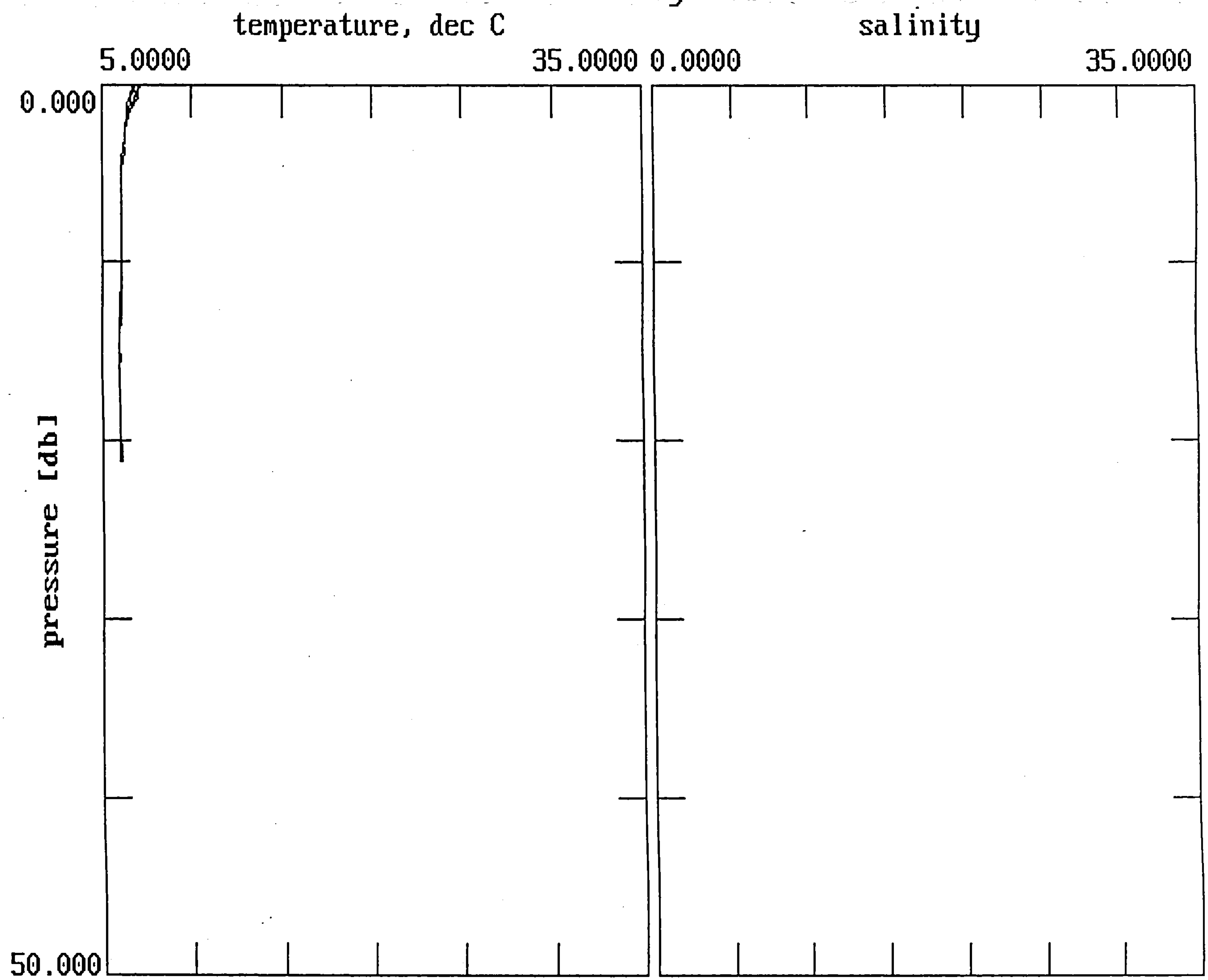


SN = 571 P = -0.062



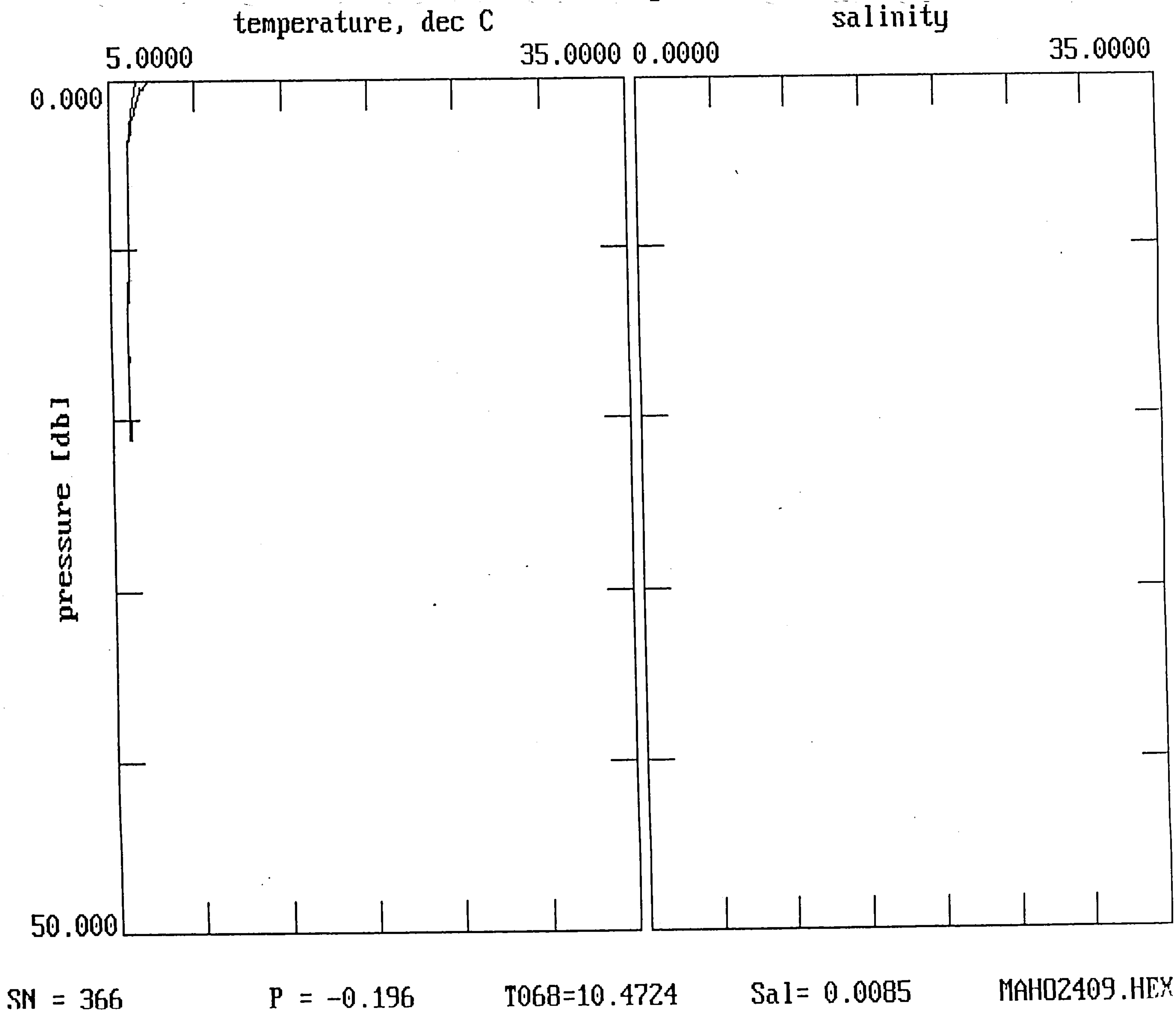
SN = 289 P = -0.545 T068=7.7432 Sal= 0.0066 MAH02402.HEX

37



SN = 445 P = -0.223 T068=10.9689 Sal= 0.0029 MAH02406.HEX

39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35.0000
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50.000
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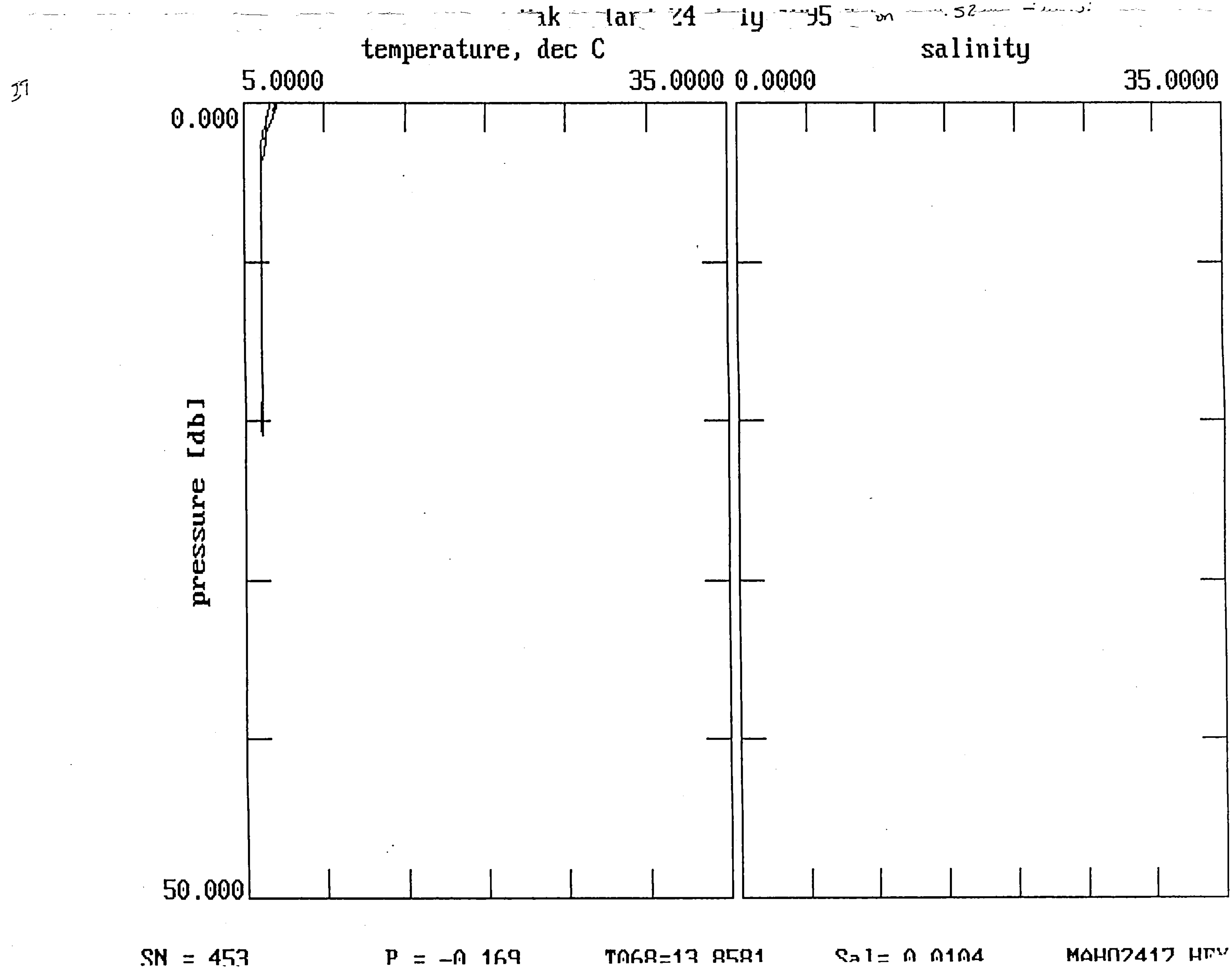
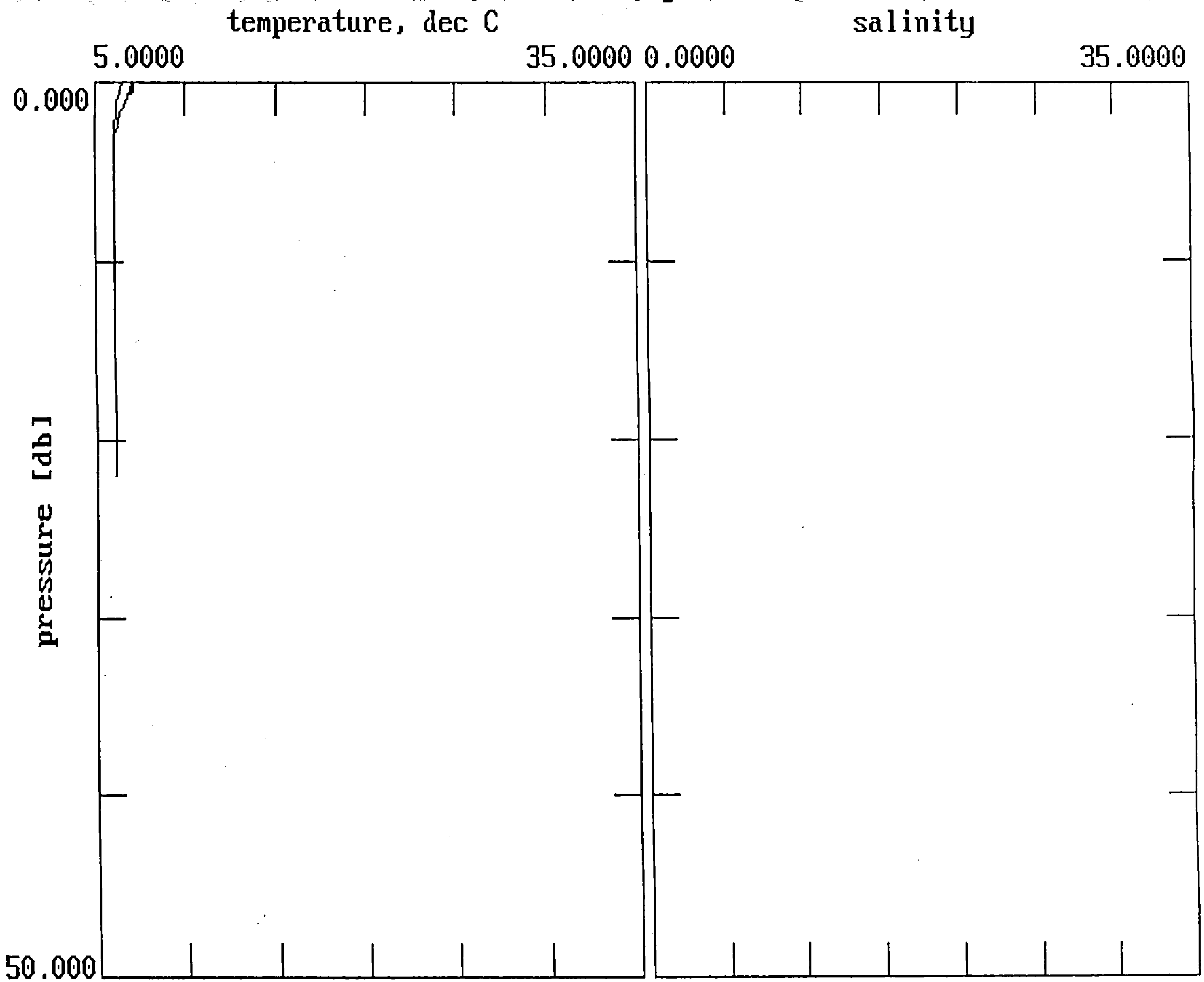
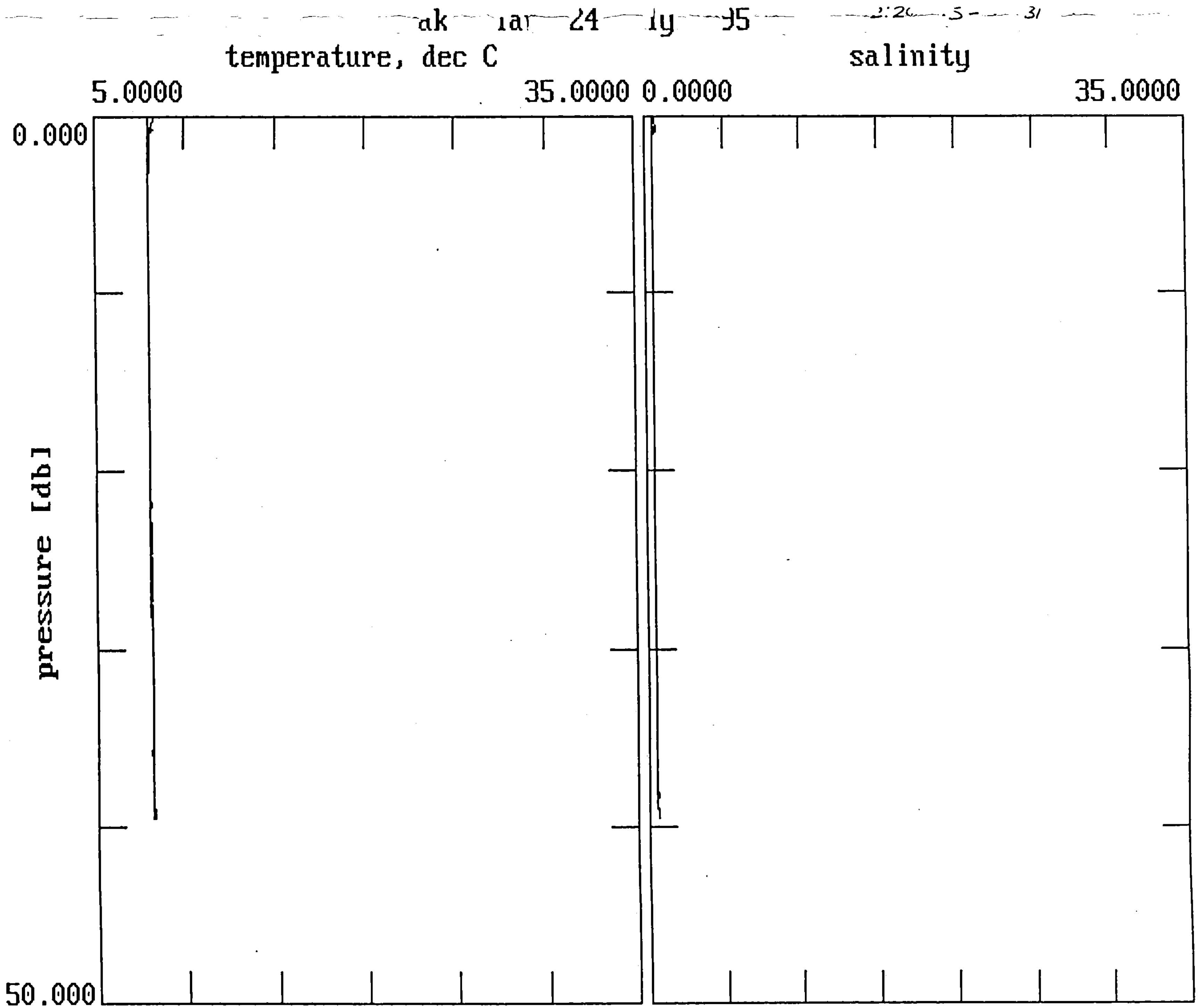
T068=10.4724
Sal= 0.0085
MAHO2409.HEX


ak lar 24 iy 95
temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
50.000
pressure [db]
SN = 453
P = -0.169
T068=13.8581
Sal= 0.0104
MAH02417.HEX

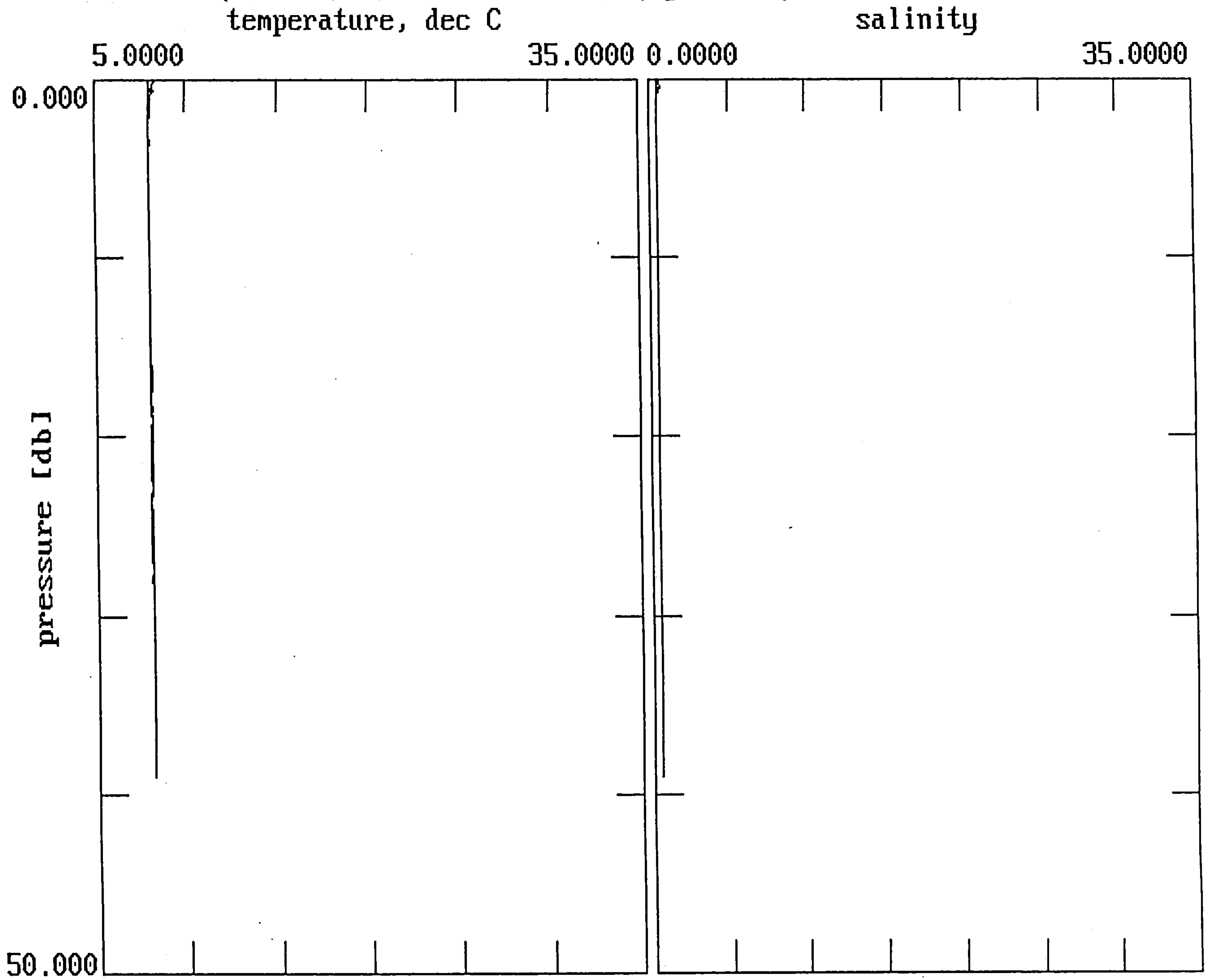
40



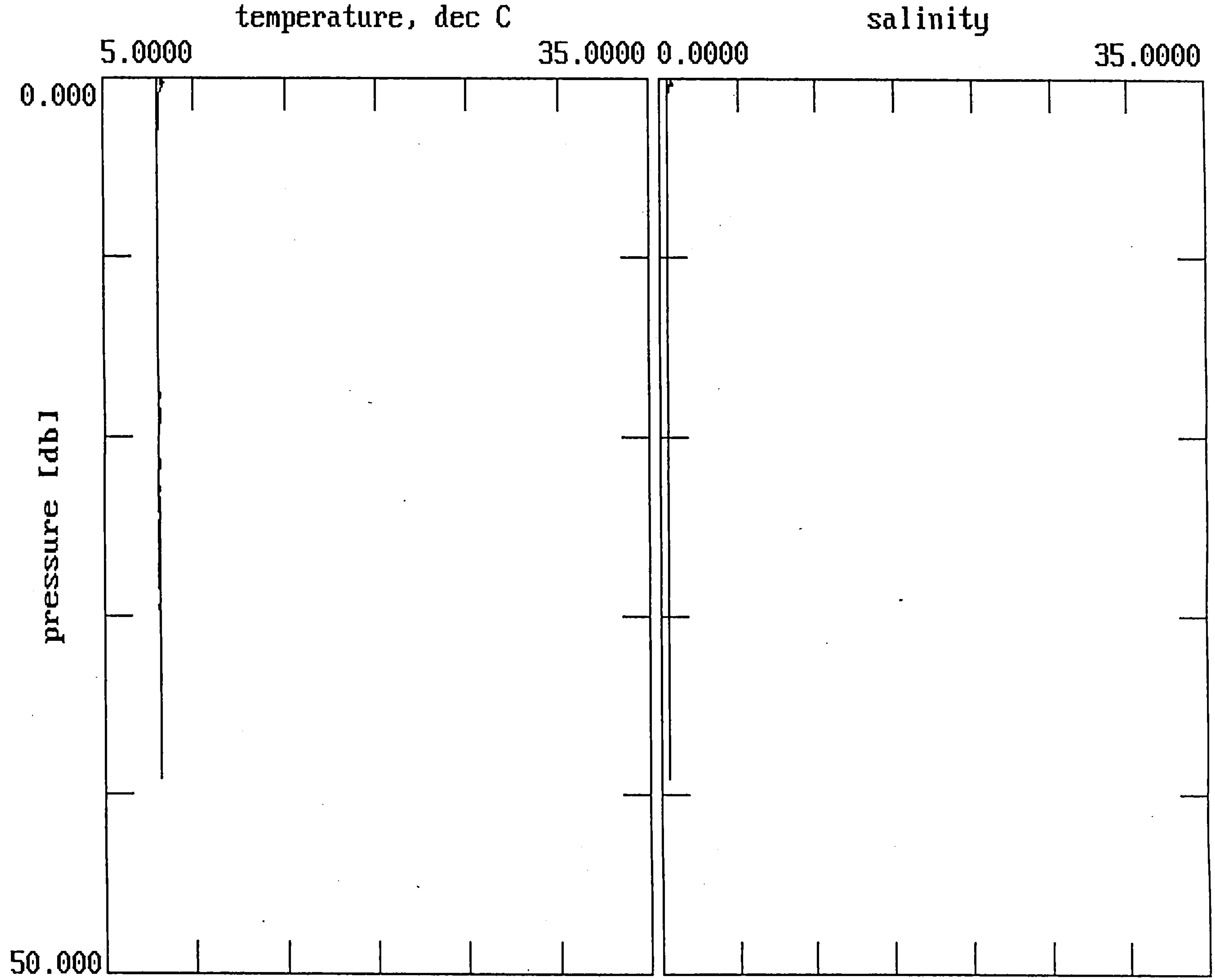
SN = 558   P = -0.196   T068=12.4942   Sal= 0.0089   MAH02422.HEX



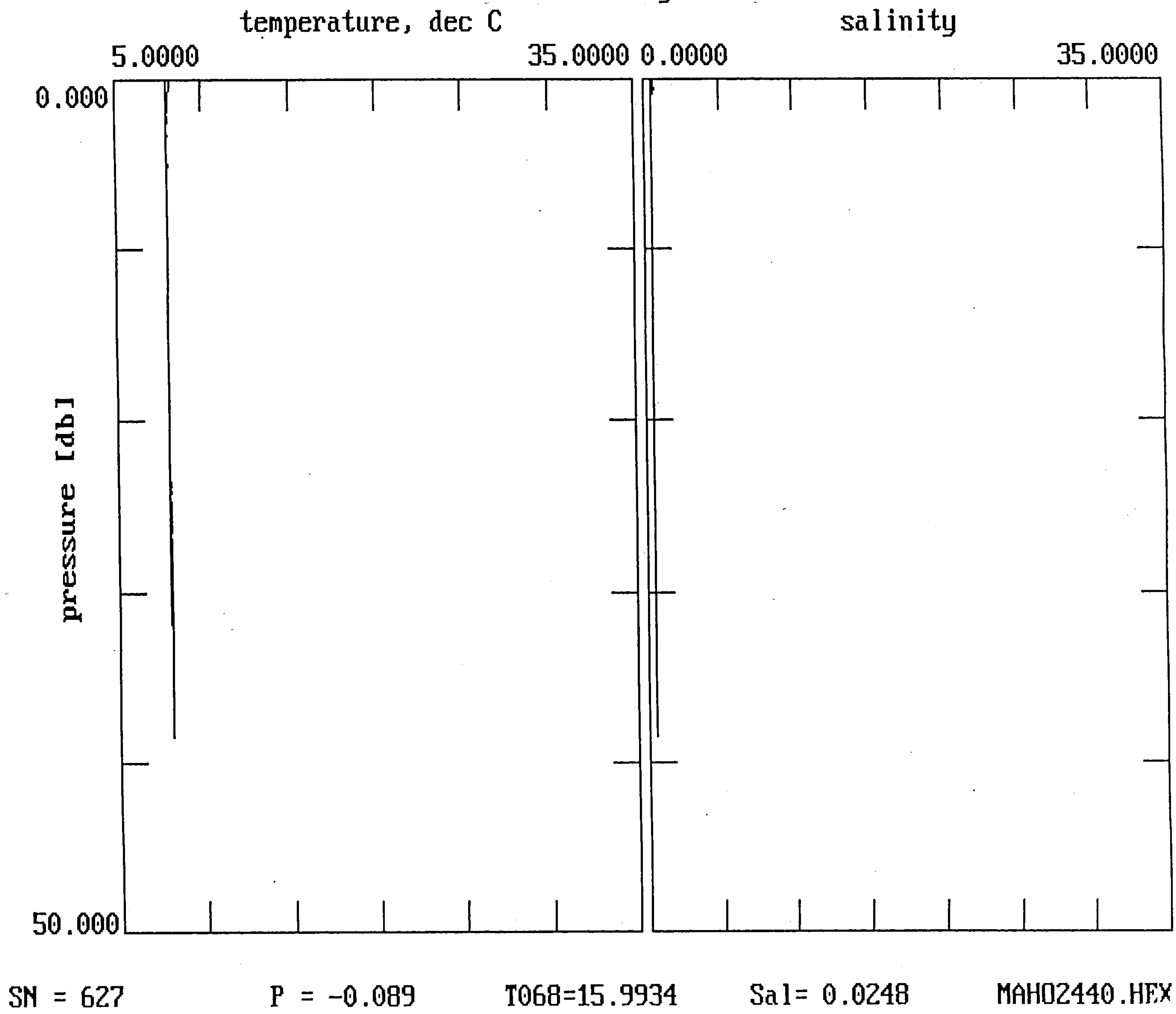
SN = 487   P = -0.196   T068=14.2475   Sal= 0.0165   MAH02420.HFX



SN = 523 P = -0.169 T068=14.1980 Sal= 0.0183 MAH02425.HEX



SN = 482 P = -0.142 T068=11.3817 Sal= 0.0164 MAH02435.HEX



temperature, dec C
salinity
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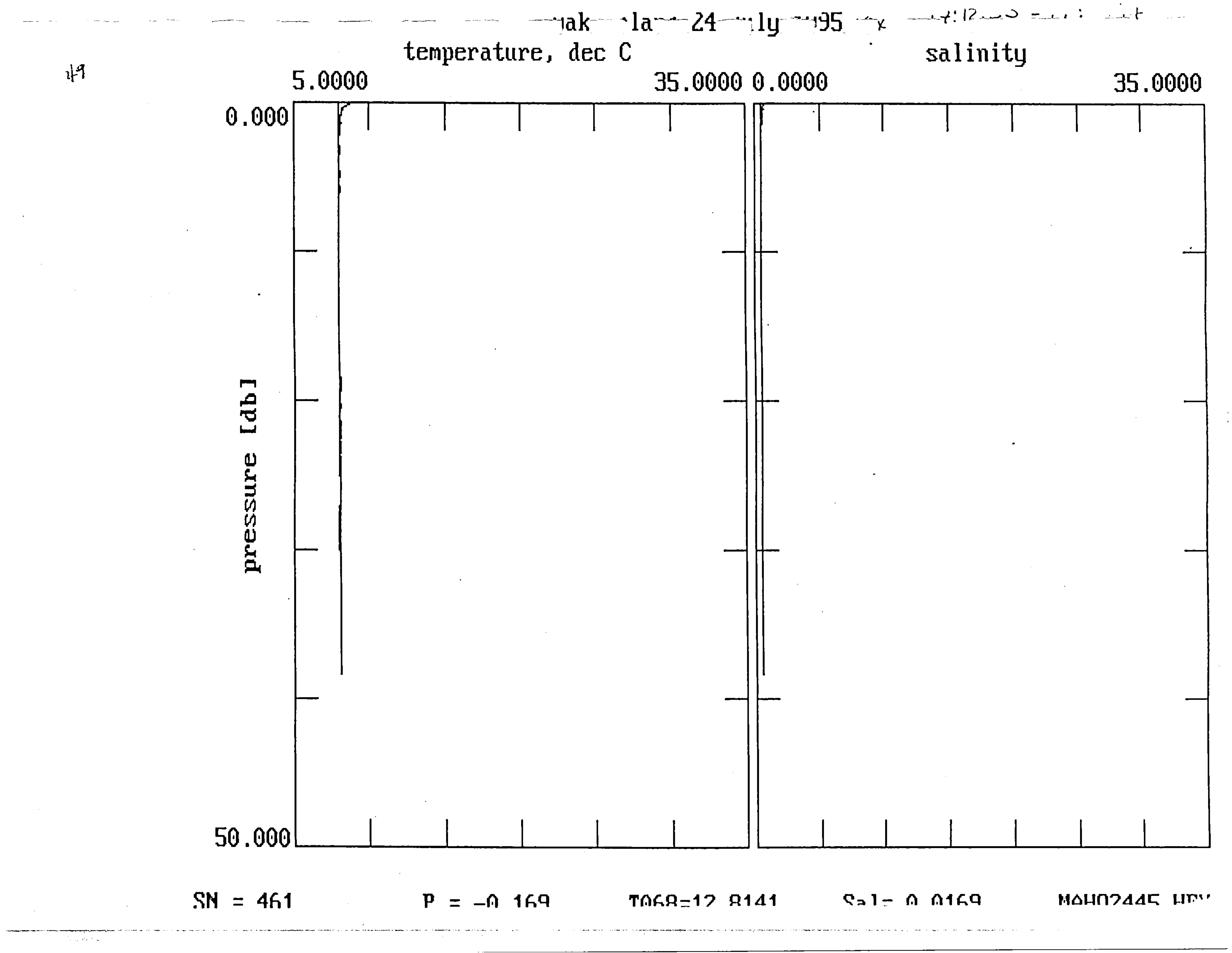
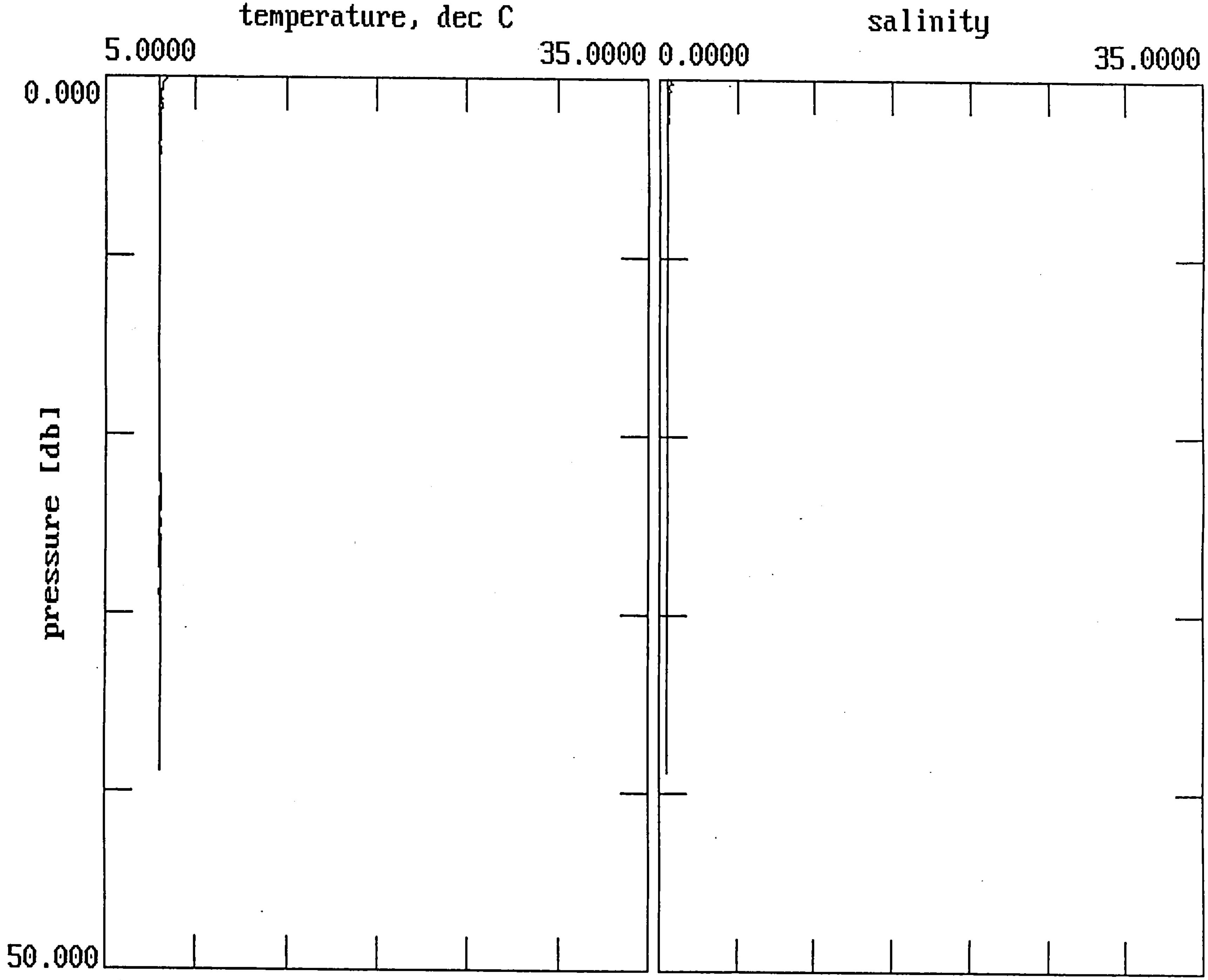
35.0000
0.000
50.000
pressure [db]
SN = 627
P = -0.089
T068=15.9934
Sal= 0.0248
MAHO2440.HEX


ak la 24 ly 95
#9
temperature, dec C
5.0000
35.0000
salinity
0.0000
35.0000
pressure [db]
0.000
50.000
SN = 461
P = -0.169
T068=12.8141
Sal= 0.0169

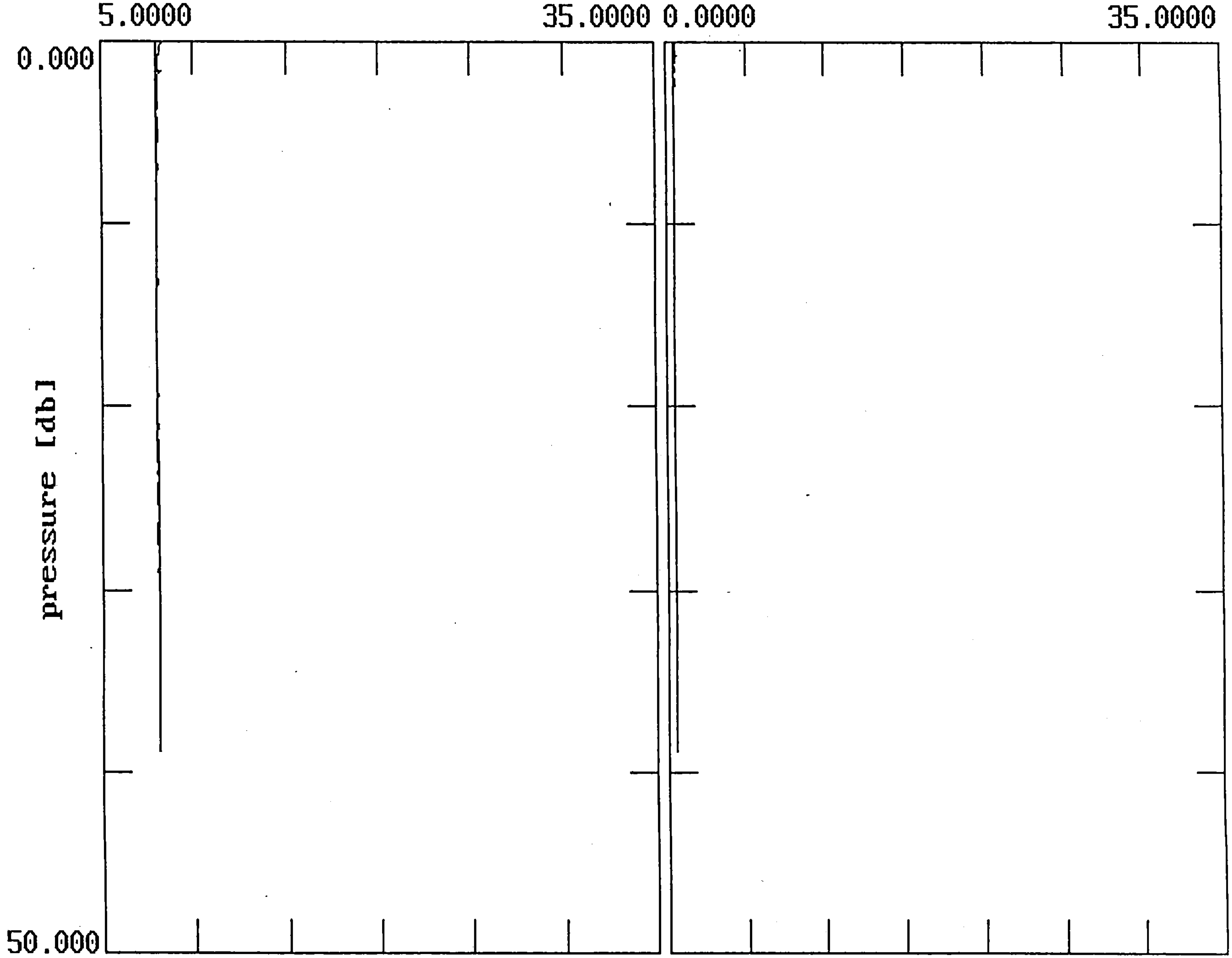
Jak ..la... 24 ..ly ..995



SN = 431 P = -0 357 T068=11 2703 Sal= 0 0164 M0H0245O ...

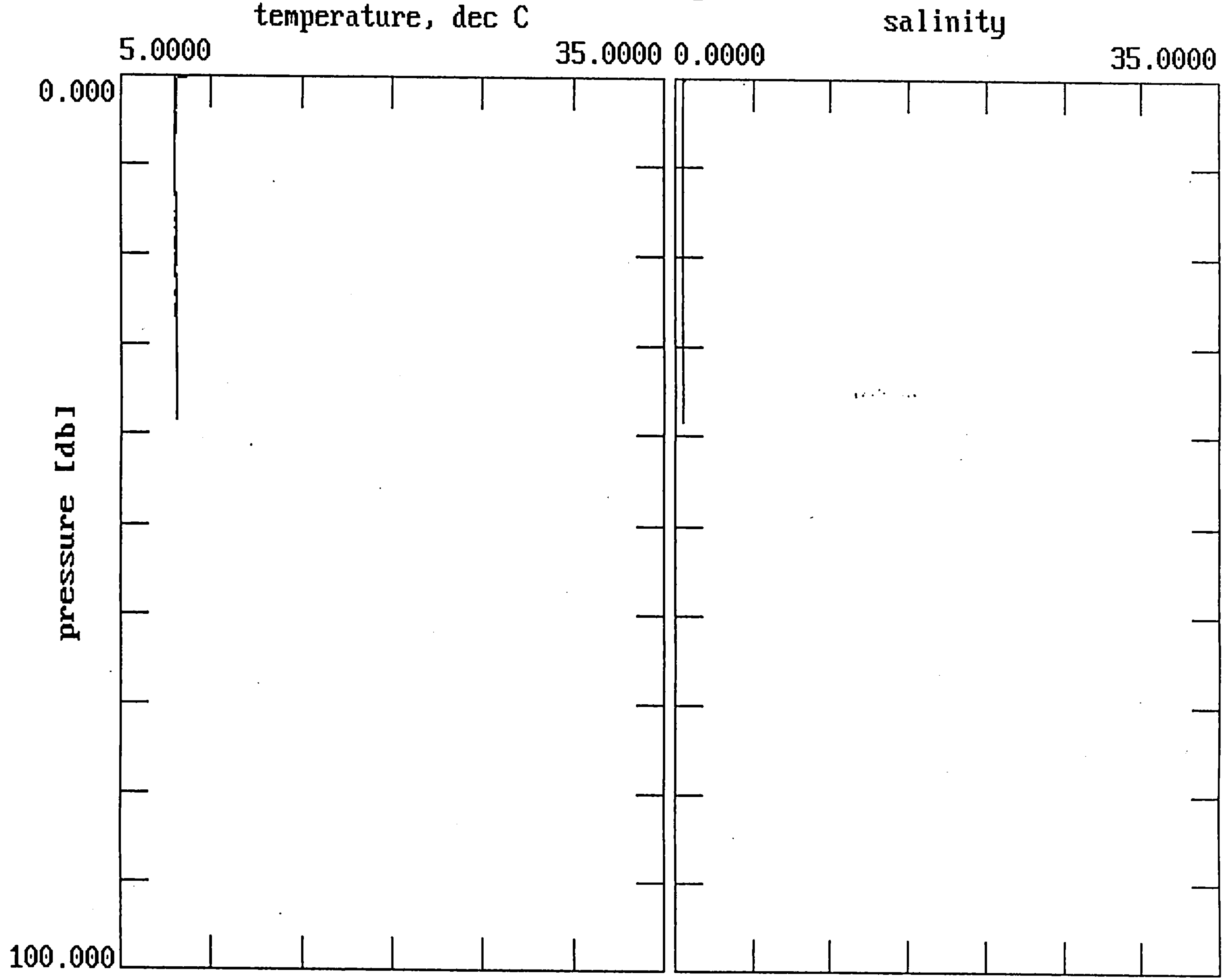
51

Jak ;la... 24 ily J95 .)x 19 50 19. 31



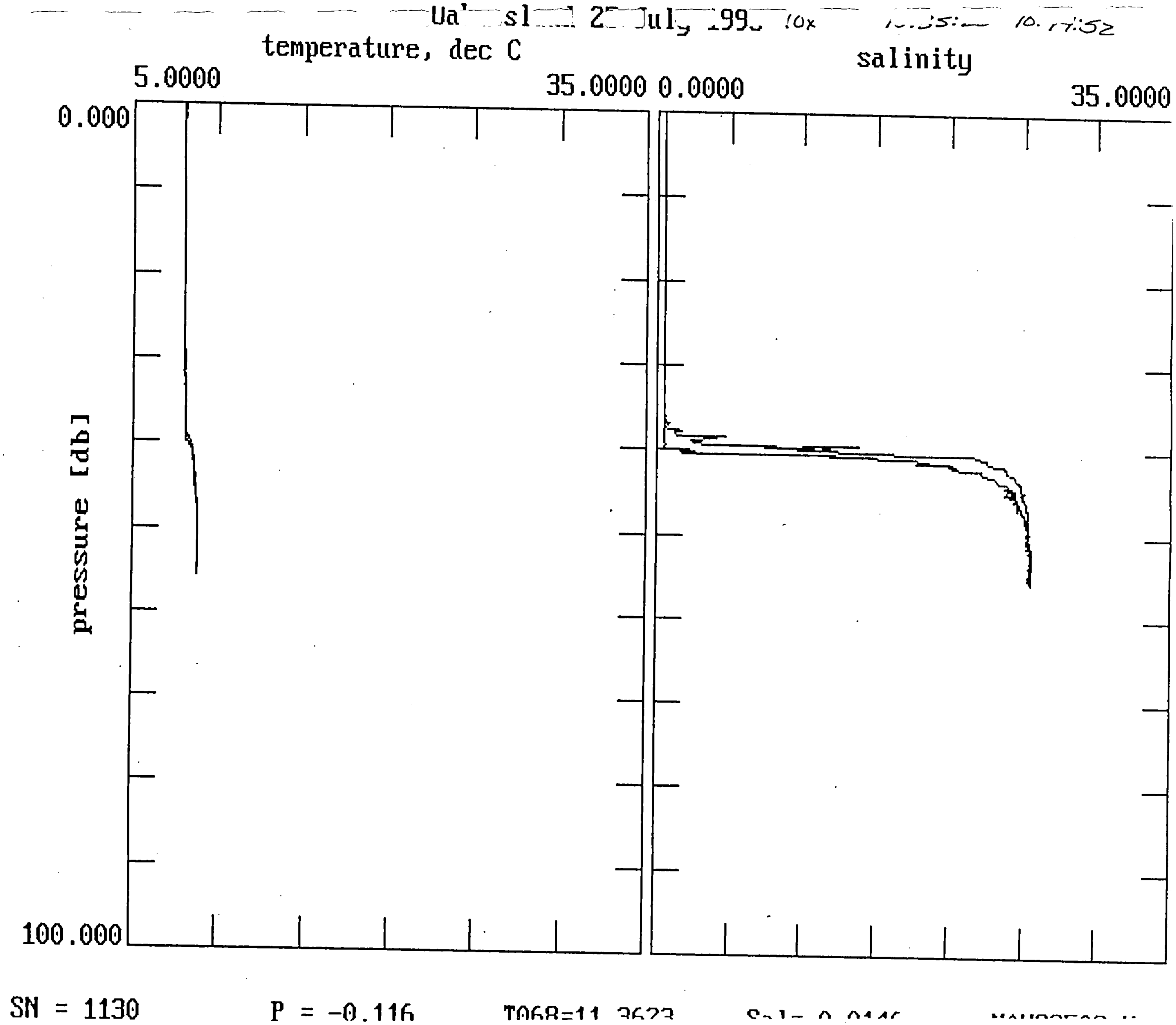
SN = 532 P = -0 142 T068=15 3030 Sal= 0 0169 MAH02455 UTV

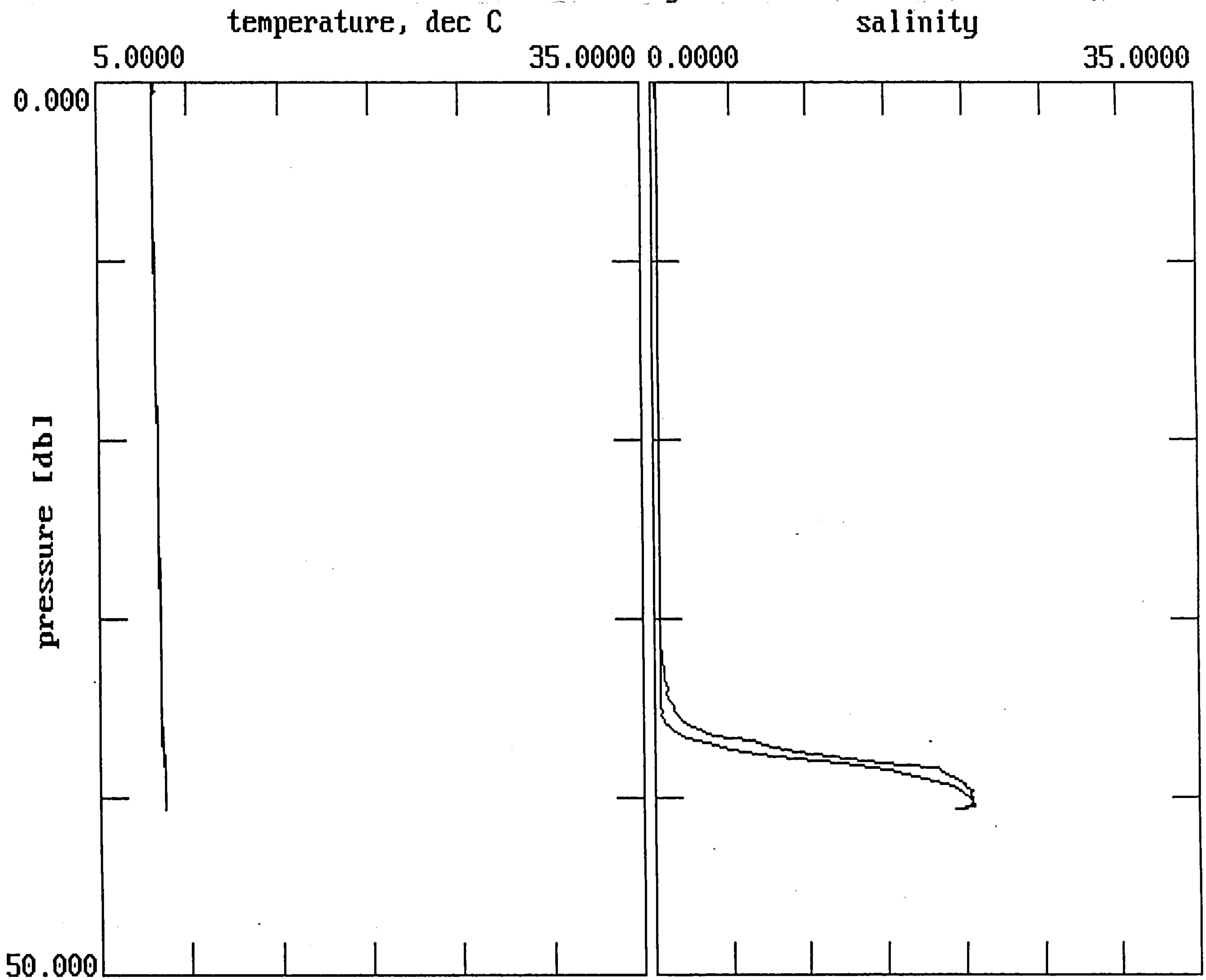
Jal. Isla... 25 July 1995



SN = 529 P = -0.035 T068=11.0790 Sal= 0.0252

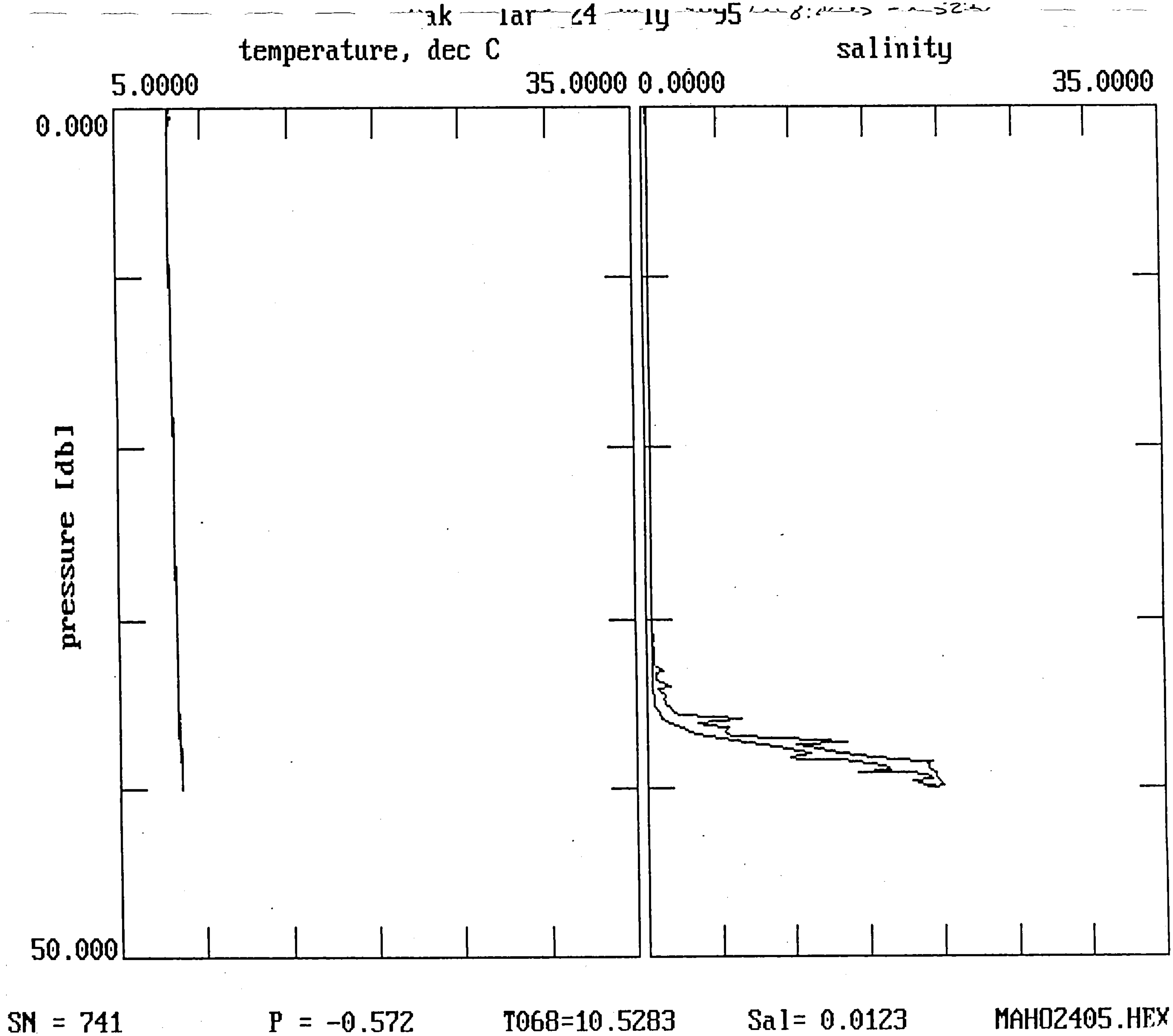
53


Ua sl 2 July 199 10x 10.17:52
temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
pressure [db]
100.000
SN = 1130
P = -0.116



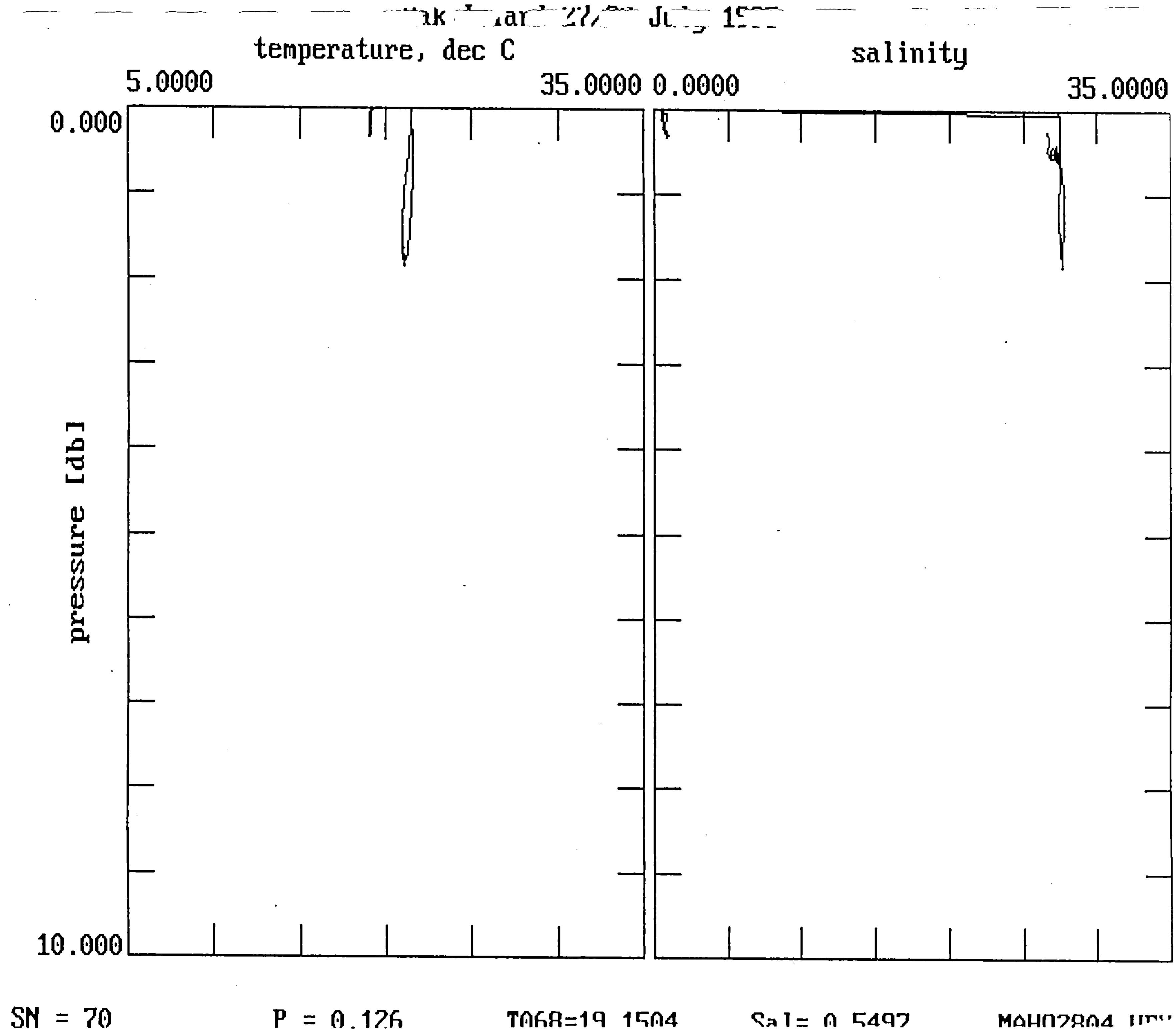
SN = 626 P = -0.518 T068=11.7172 Sal= 0.0147 MAHO2401.HEX

55



temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
pressure [db]
50.000
SN = 741
P = -0.572
T068=10.5283
Sal= 0.0123
MAH02405.HEX

Attachment C: CTD casts in nearshore.


temperature, dec C
salinity
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35.0000
0.0000
35.0000
0.000
10.000
pressure [db]
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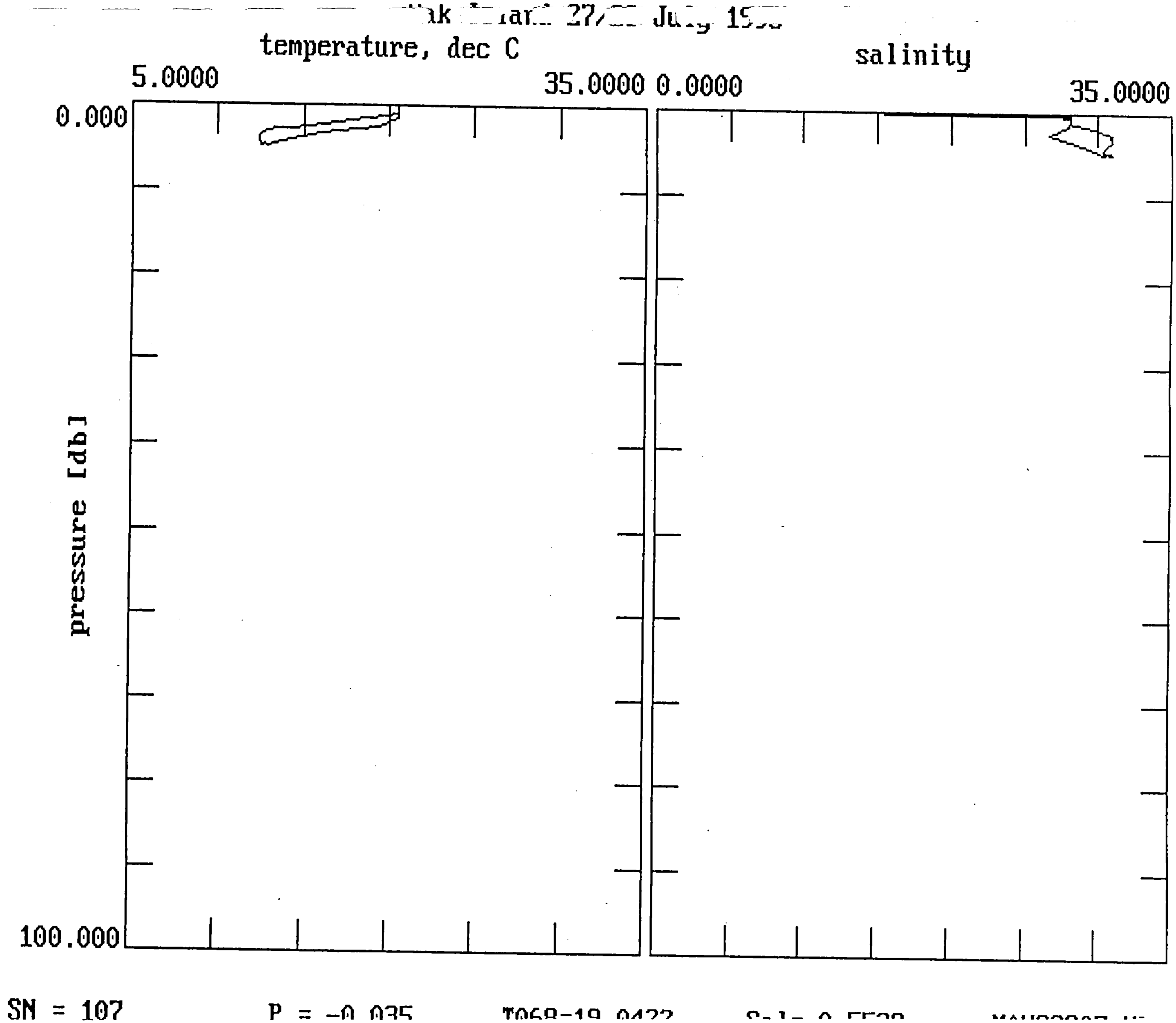
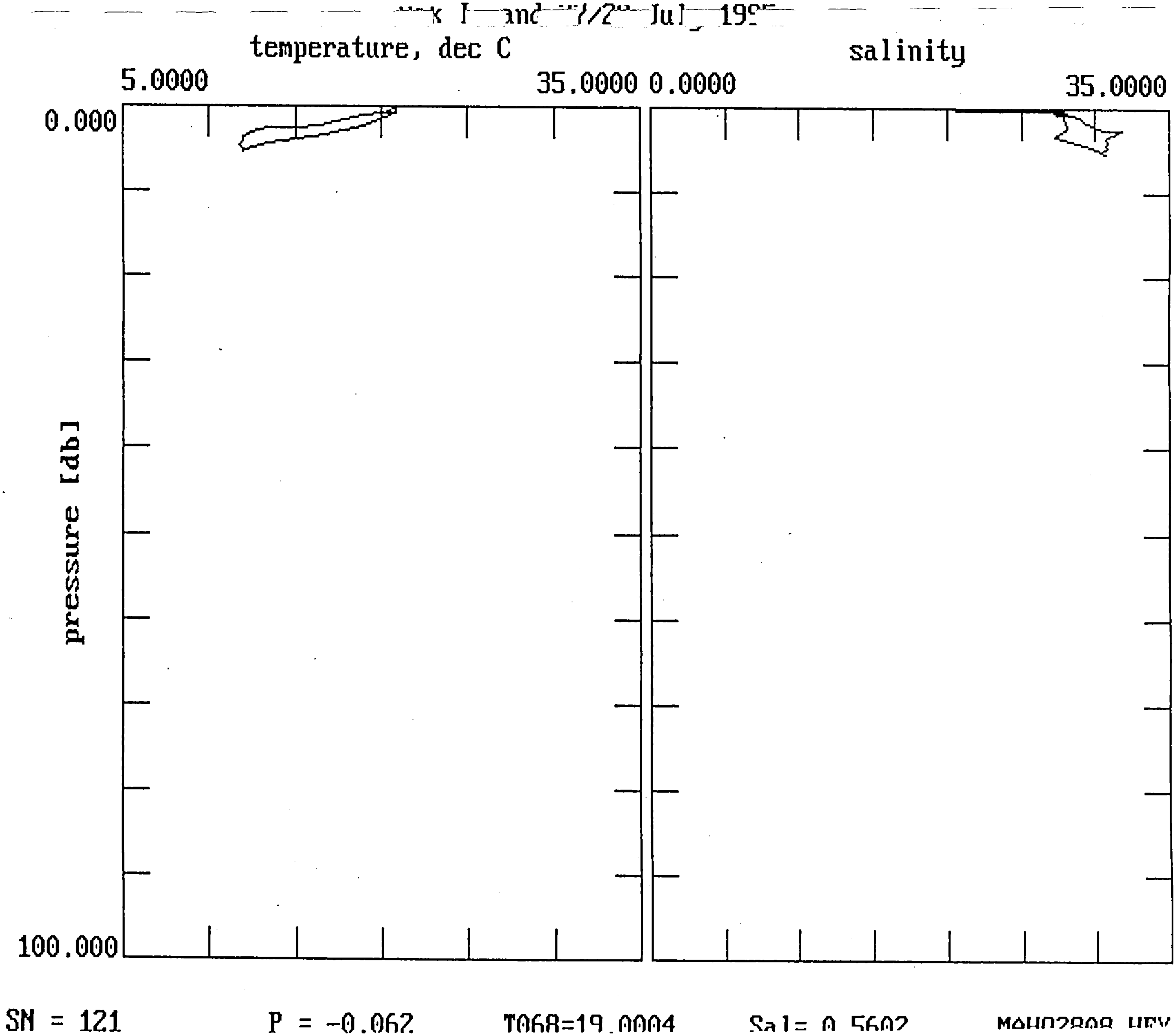
P = 0.126
T068=19.1504
Sal= 0.5497


July
temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
100.000
pressure [db]
SN = 107


temperature, dec C
5.0000
35.0000
salinity
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35.0000
0.000
100.000
pressure [db]
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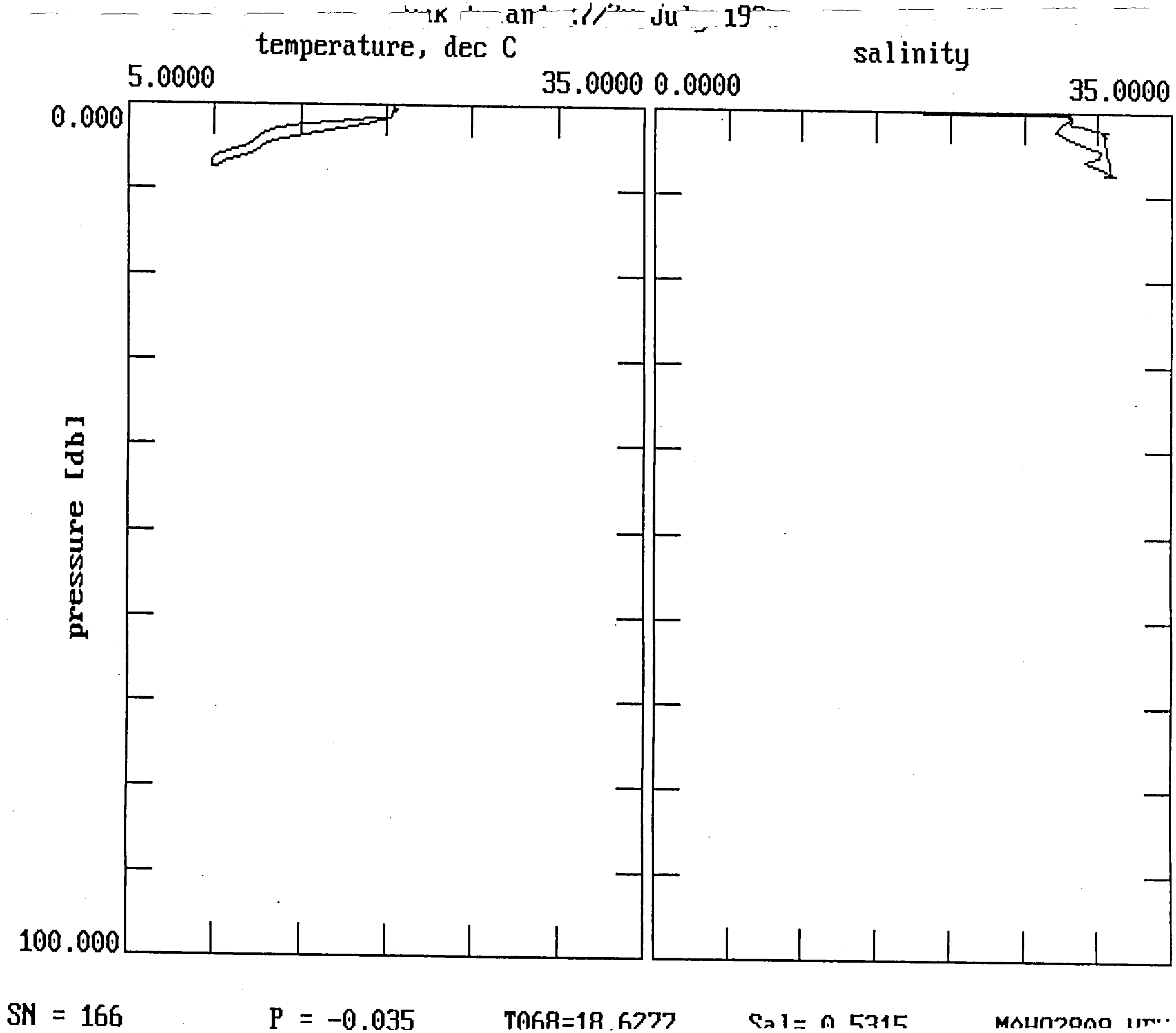
T068=19.0004
Sal= 0.5602


temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
100.000
pressure [db]
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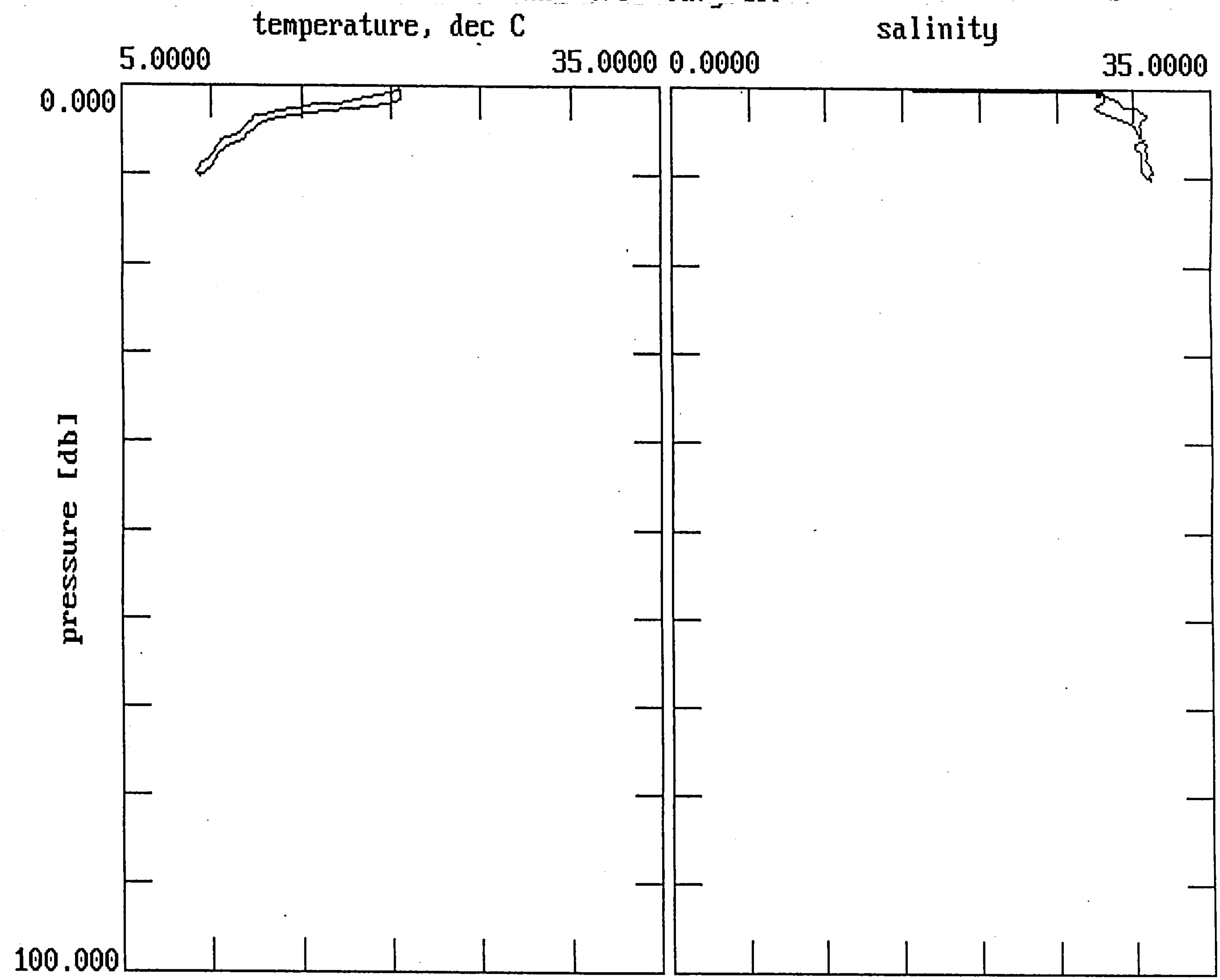
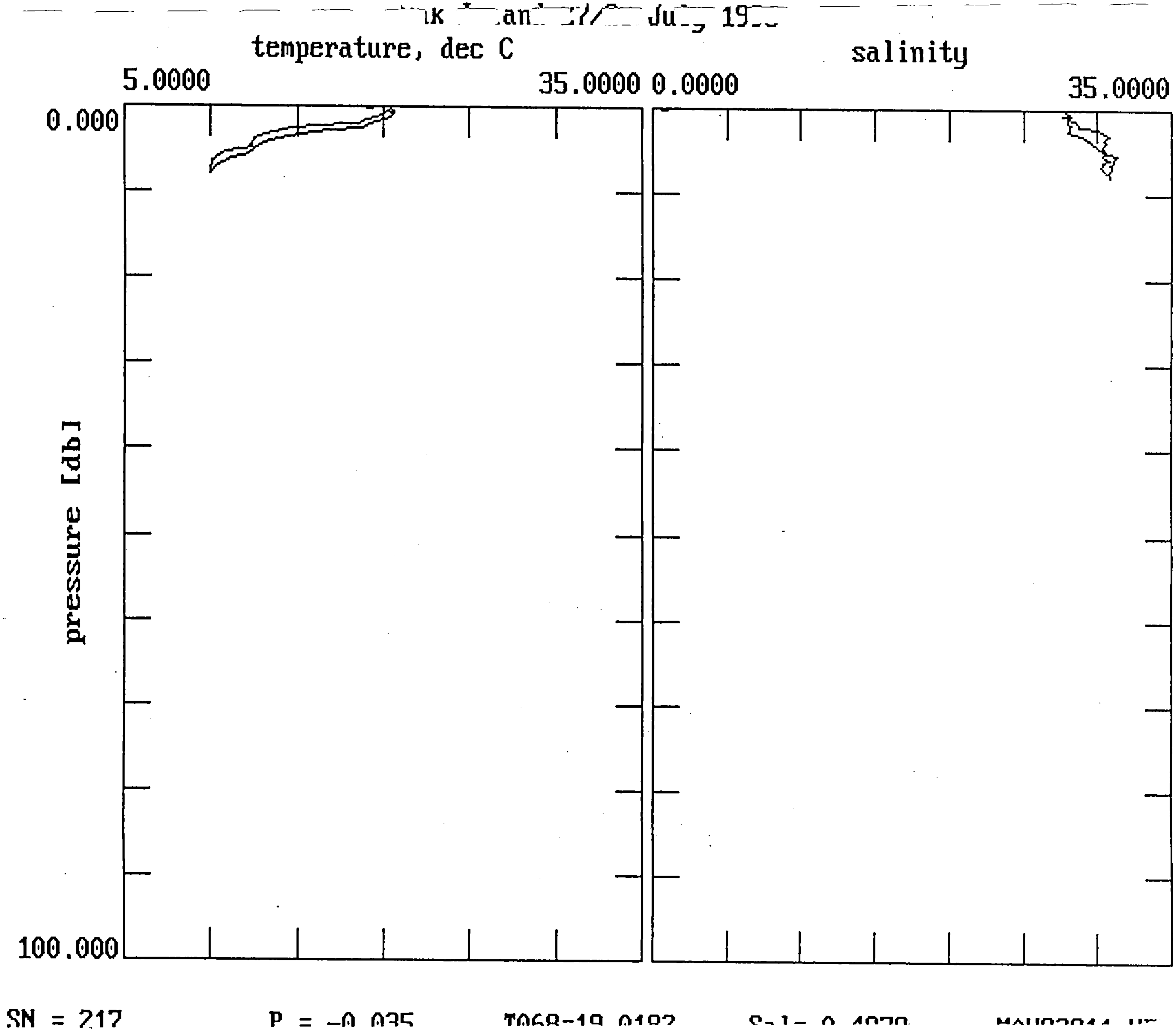
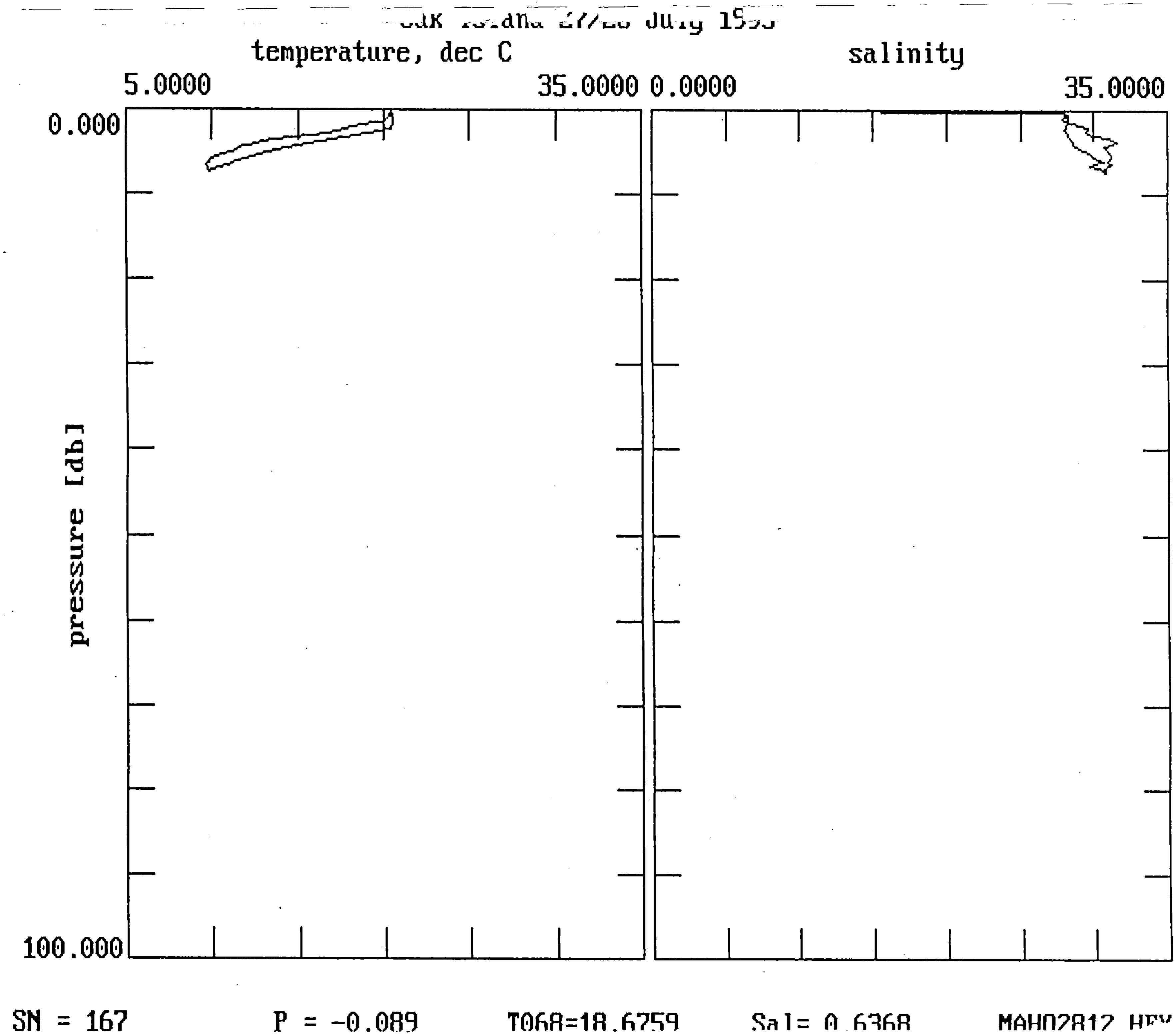
P = -0.035



SN = 202 P = -0.008 T068=18.9224 Sal= 0.5328 MAH02810.HEX


temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
100.000
pressure [db]
SN = 217
P = -0.035


temperature, dec C
5.0000
35.0000
salinity
0.0000
35.0000
0.000
100.000
pressure [db]
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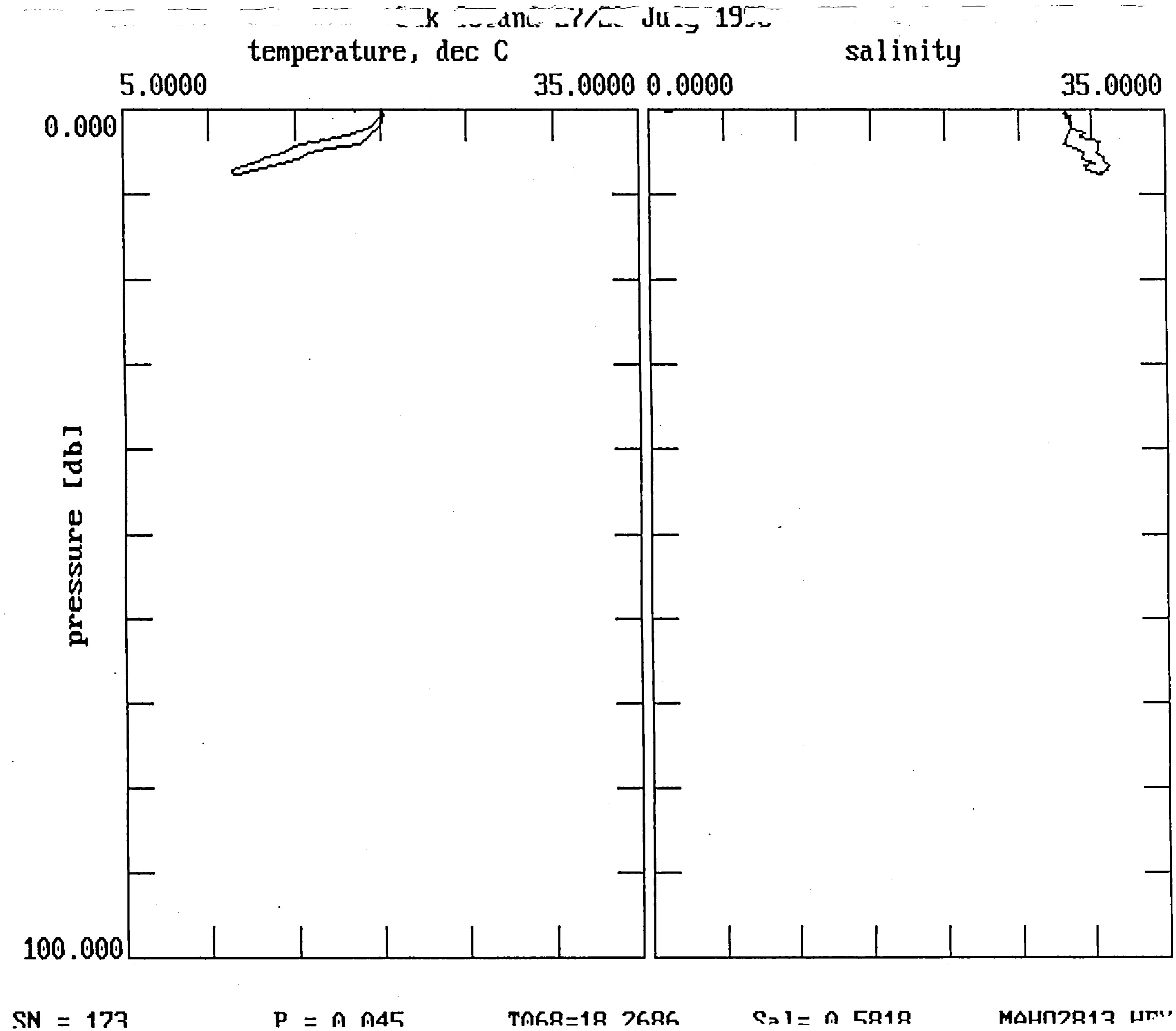
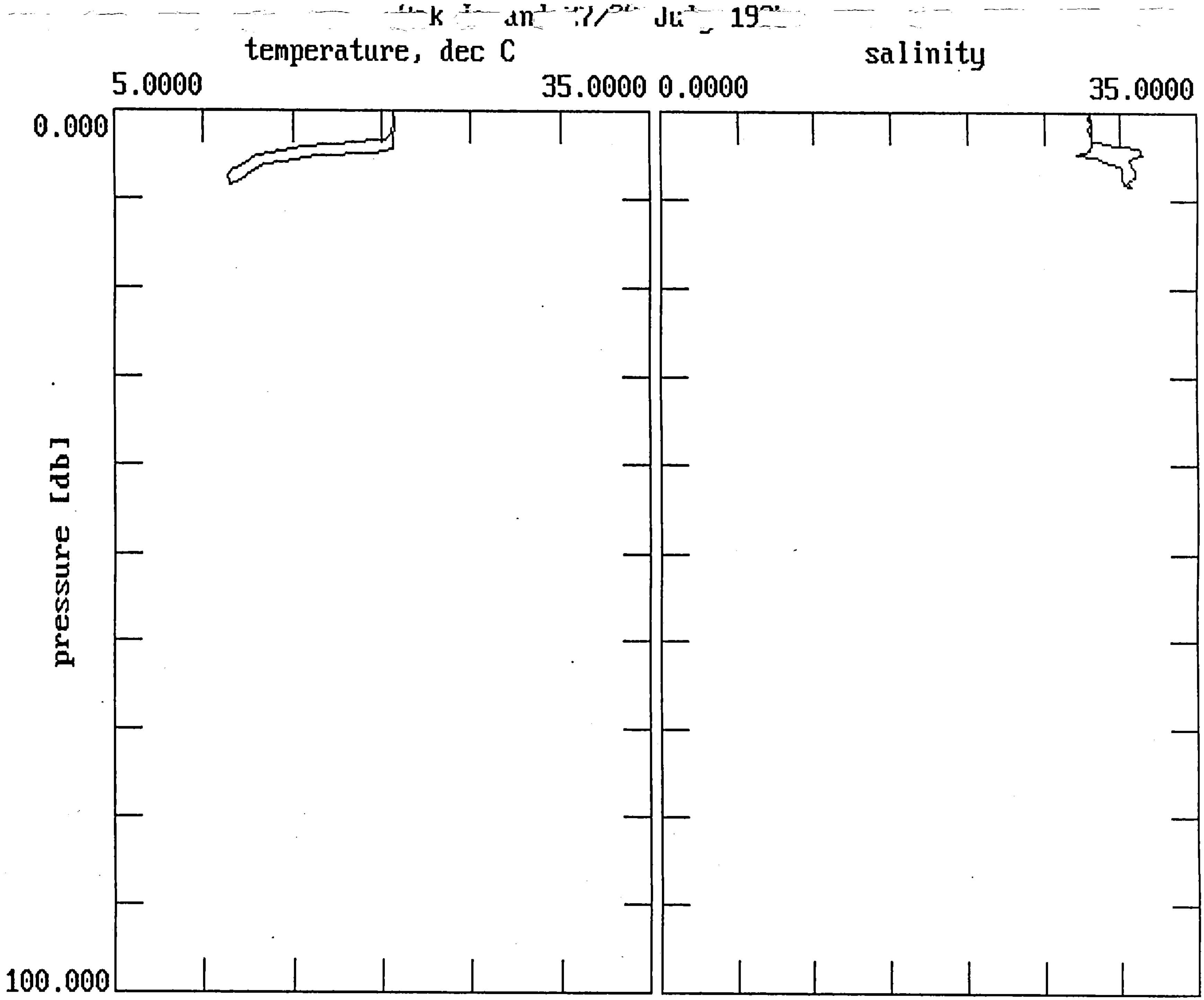
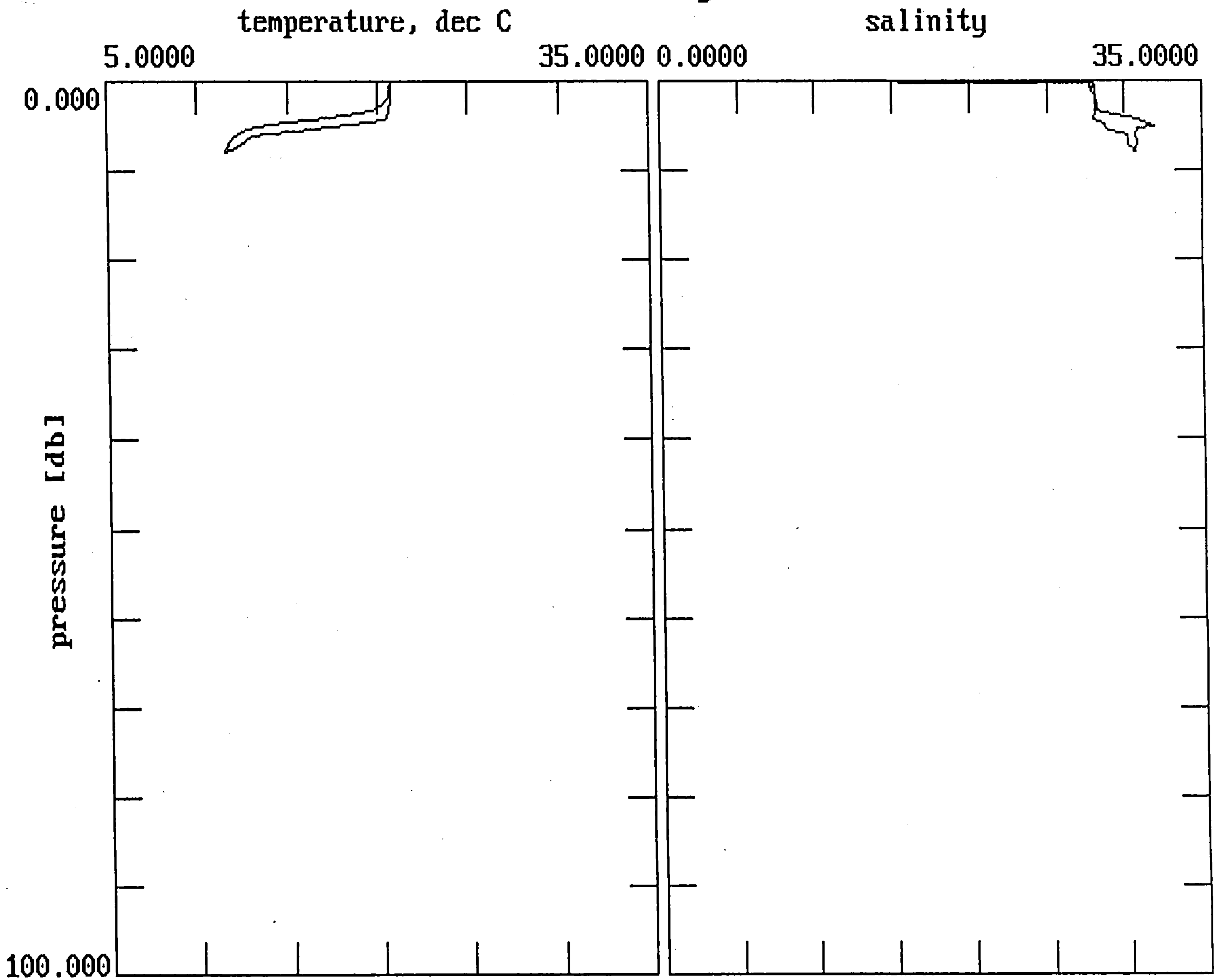
P = -0.089
T068=18.6759
Sal= 0.6368
MAH02812 HEX



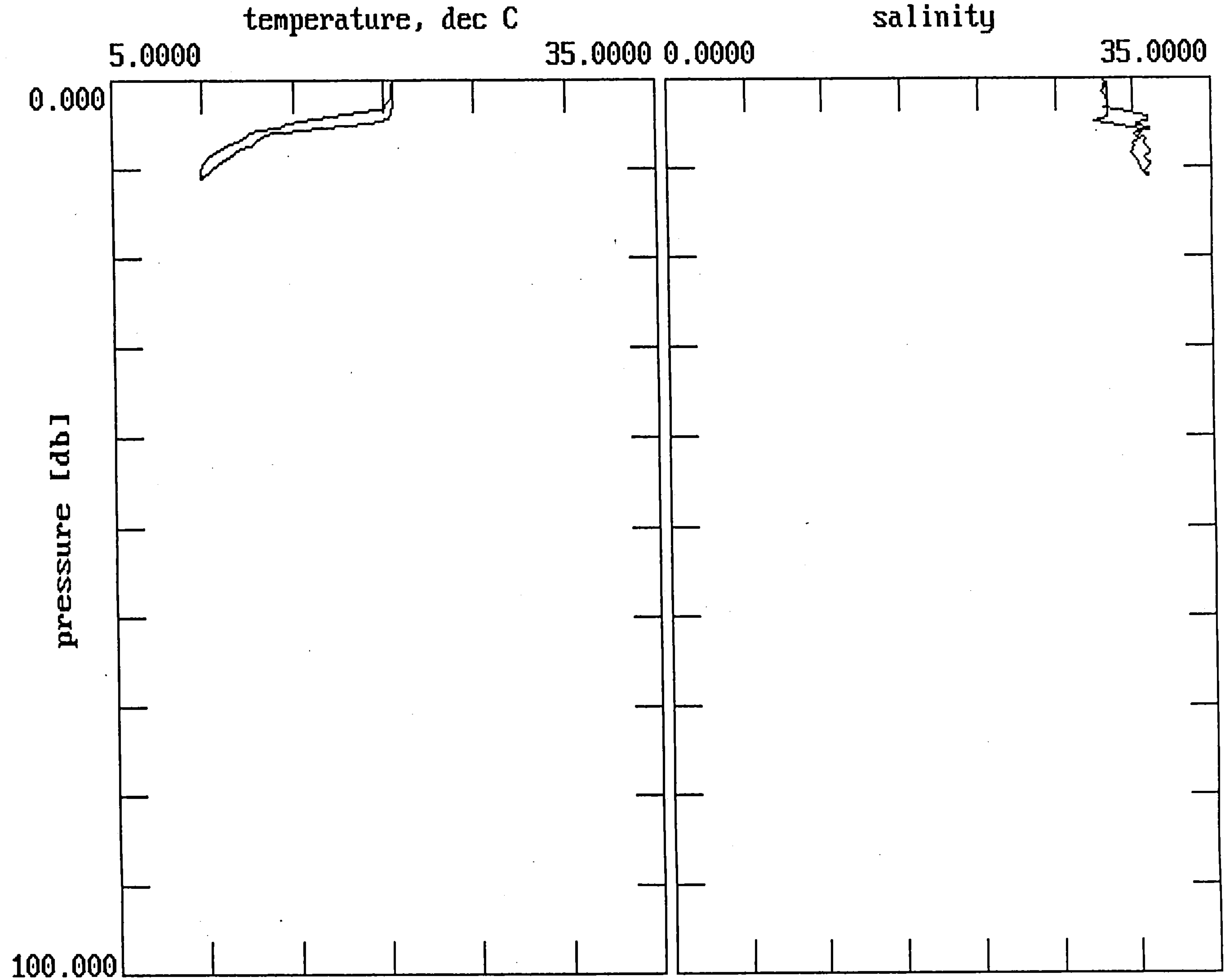
k anc 27/ Ju 19
temperature, dec C
salinity
5.0000
35.0000
0.0000
35.0000
0.000
pressure [db]
100.000
SN = 173
P = 0.045
T068=18.2686
Sal= 0.5818
MAH02813.HEX



SN = 187 P = -0.008 T068=19.3400 Sal= 0.5560 MAH02814 HEV



SN = 185 P = -0.008 T068=18.2980 Sal= 0.5138 MAH02815.HFX



SN = 253 P = -0.035 T068=18.8234 Sal= 0.4628 MAH02816.HEX

Attachment D: Radiocarbon reports from the National Ocean Sciences AMS Facility at the Woods Hole Oceanographic Institution

lenn A. Jones
irector – Ext. 2585
Robert J. Schneider
ssoc. Director – Ext. 2756
arl F. von Reden
taff Physicist – Ext. 3384
nn P. McNichol
taff Chemist – Ext. 3394

NATIONAL OCEAN SCIENCES AMS FACILITY

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543-1539
Phone: (508) 457-2000 x 2585
Fax: (508) 457-2183

November 30, 1995

REPORT #: 95-095

Dr. David Aubrey
Dept. G&G
Mail Stop 22
W.H.O.I.

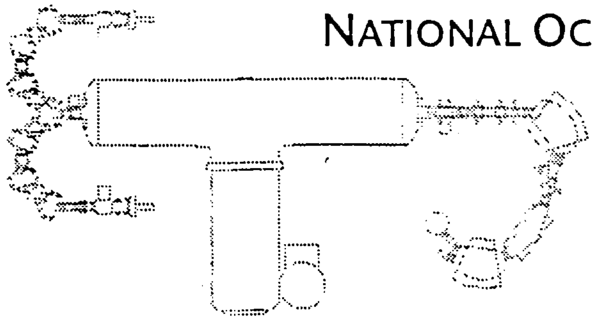
Dear Dave,

Please find the enclosed NOSAMS ^{14}C Results Report on 4 of your 7 samples from Oak Island, Nova Scotia. There will be no charge for these analyses; it will be considered in-house research. Should you have any questions regarding your results please contact me.

Sincerely,

Robert J. Schneider, Acting Director
National Ocean Sciences AMS Facility

Glenn A. Jones
Director – Ext. 2585
Robert J. Schneider
Assoc. Director – Ext. 2756
Karl F. von Reden
Staff Physicist – Ext. 3384
Ann P. McNichol
Staff Chemist – Ext. 3394



NATIONAL OCEAN SCIENCES AMS FACILITY

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543-1539
Phone: (508) 457-2000 x 2585
Fax: (508) 457-2183

Data Report #95-095

Radiocarbon Results: Dr. David Aubrey/Gutierrez

11/30/95

A.P. McNichol, Radiocarbon Analyst
National Ocean Sciences
AMS Facility

General Statement of ^{14}C Procedures
at the National Ocean Sciences AMS Facility

All laboratory preparations for AMS radiocarbon analyses of submitted samples occur in the NOSAMS Sample Preparation Lab unless otherwise noted on the attached report of Final Results. Procedures appropriate to the raw material being analyzed include: acid hydrolysis (HY), combustion (OC), or stripping of CO_2 gas from water (WS) samples. Carbon dioxide, whether submitted (GS) or generated at the NOSAMS Facility, reacted to form graphite using an Fe/H_2 catalytic-reduction. Graphite is pressed into targets which are analyzed on the accelerator along with standards and process blanks. Two primary standards are used during all ^{14}C measurements: NBS Oxalic Acid I (NIST-SRM-4990) and Oxalic Acid II (NIST-SRM-4990C). The ^{14}C activity ratio of Oxalic Acid II ($\delta^{13}C$ = -17.3 per mil) to Oxalic Acid I ($\delta^{13}C$ = -19.0 per mil) is taken to be 1.293. Every group of samples processed includes an appropriate blank which is analyzed concurrently with the group. Process blank materials include IAEA C-1 Carrarra marble for inorganic carbon and gas samples; a Johnson-Mathey 99.9999% graphite powder for organic carbon samples; and a commercial tank of ^{14}C- free CO_2 for seawater samples.

Fraction Modern (F_m) is a measurement of the deviation of the $^{14}C/C$ ratio of a sample from "modern." Modern is defined as 95% of the radiocarbon concentration (in AD 1950) of NBS Oxalic Acid I normalized to $\delta^{13}C_{VPDB}$ = -19 per mil (Olsson, 1970). AMS results are calculated using the internationally accepted modern value of $1.176 \pm 0.010 \times 10^{-12}$ (Karlen, *et. al.*, 1968) and a final ^{13}C-correction is made to normalize the sample F_m to a $\delta^{13}C_{VPDB}$ value of -25 per mil.

Stable isotope measurements of sample $\delta^{13}C$ used to correct F_m values are typically made at the NOSAMS Facility by analyzing sub-samples of the CO_2 gas generated during graphite production with either a VG PRISM or VG OPTIMA mass spectrometer. However, most carbonate samples are reacted and measured directly with the VG PRISM ISOCARB. The $\delta^{13}C$ value used to calculate the F_m of a sample is specified in the report of Final Results.

Reporting of ages and/or activities follows the convention outlined by Stuiver and Polach (1977) and Stuiver (1980). Radiocarbon ages are calculated using 5568 (yrs) as the half-life of radiocarbon and are reported without reservoir corrections or calibration to calendar years. For all sea water samples, where collection date is known, or for other samples where the age is known, such as wood from tree rings, live-collected molluscs, or corals, a $\Delta^{14}C$ activity which has been corrected to 1950 values is also reported.

Atoms of ^{14}C contained in a sample are directly counted using the AMS method of radiocarbon analysis, therefore, internal statistical errors are calculated using the number of counts measured from each target. An external error is calculated from the reproducibility of individual analyses for a given target. The error reported is the larger of the internal or external errors.

When reporting AMS results of samples run at the NOSAMS facility, accession numbers (e.g. OS-####'s) are required to be listed together with the results. To avoid confusion, we suggest tabulating OS-numbers and associated radiocarbon ages as they appear on the attached Final Report in addition to any subsequent corrections that may need to be made to the ages. We ask that published results acknowlege support from NSF by including the NSF Cooperative Agreement number, OCE 801015. The NOSAMS facility would appreciate receiving reprints or preprints of papers referencing AMS analyses made at the NOSAMS facility.

Any sample material not consumed during sample preparation or AMS radiocarbon analysis is permanently archived at the NOSAMS Facility unless other arrangements are made by the submitter.

REFERENCES

Karlen, I., Olsson, I.U., Kallburg, P. and Kilici, S., 1968. Absolute determination of the activity of two ^{14}C dating standards. Arkiv Geofysik, 4:465-471.

Olsson, I.U., 1970. The use of Oxalic acid as a Standard. *In* I.U. Olsson, ed., Radiocarbon Variations and Absolute Chronology, Nobel Symposium, 12th Proc., John Wiley & Sons, New York, p. 17.

Stuiver, M. and Polach, H.A., 1977. Discussion: Reporting of ^{14}C data. Radiocarbon, 19:355-363.

Stuiver, M., 1980. Workshop on ^{14}C data reporting. Radiocarbon, 22:964-966.

...iple ...riptic

Please Note Receipt Numbers

Receipt	Kind	Type	Submitter Type	Submitter ID	Description
10166	Biological	Wood	Oak Island, Nova Scotia	OI-W7	wood
10167	Biological	Plant	Oak Island, Nova Scotia	OI-5-CF3	coconut Fiber
10168	Biological	Plant	Oak Island, Nova Scotia	OI-3CF2	coconut Fiber
10170	Biological	Plant	Oak Island, Nova Scotia	OI-BP-8	peat

Glenn A. Jones
Director – Ext. 2585

Robert J. Schneider
Assoc. Director – Ext. 2756

Karl F. von Reden
Staff Physicist – Ext. 3384

Ann P. McNichol
Staff Chemist – Ext. 3394

NATIONAL OCEAN SCIENCES AMS FACILITY

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
Phone: (508) 548-1400 Ext. 2585
Telemail: WHAMS.C14
Fax: (508) 457-2183

To: Dave Aubrey

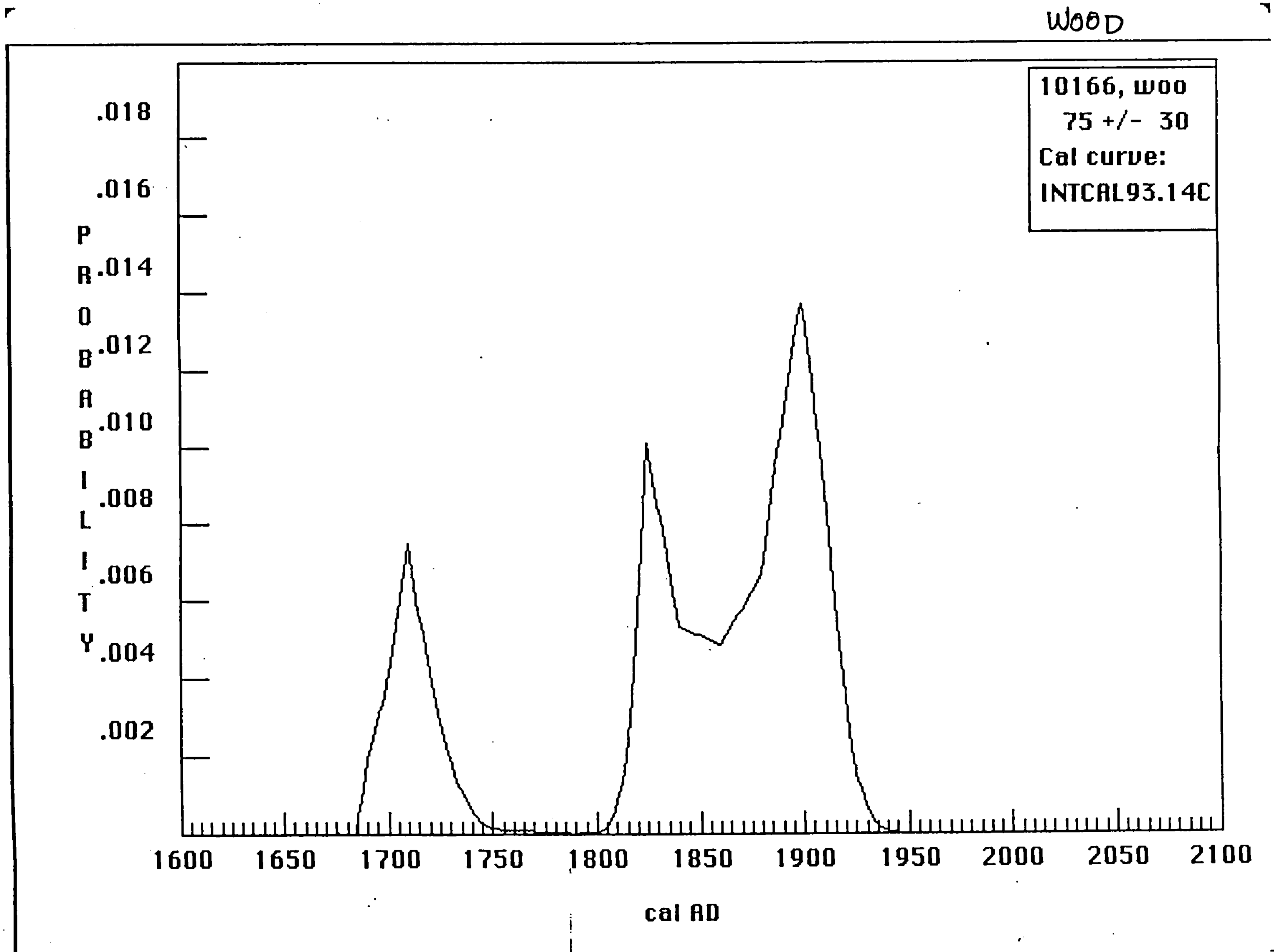
Date: December 4, 1995

From: Ann McNichol AMcN

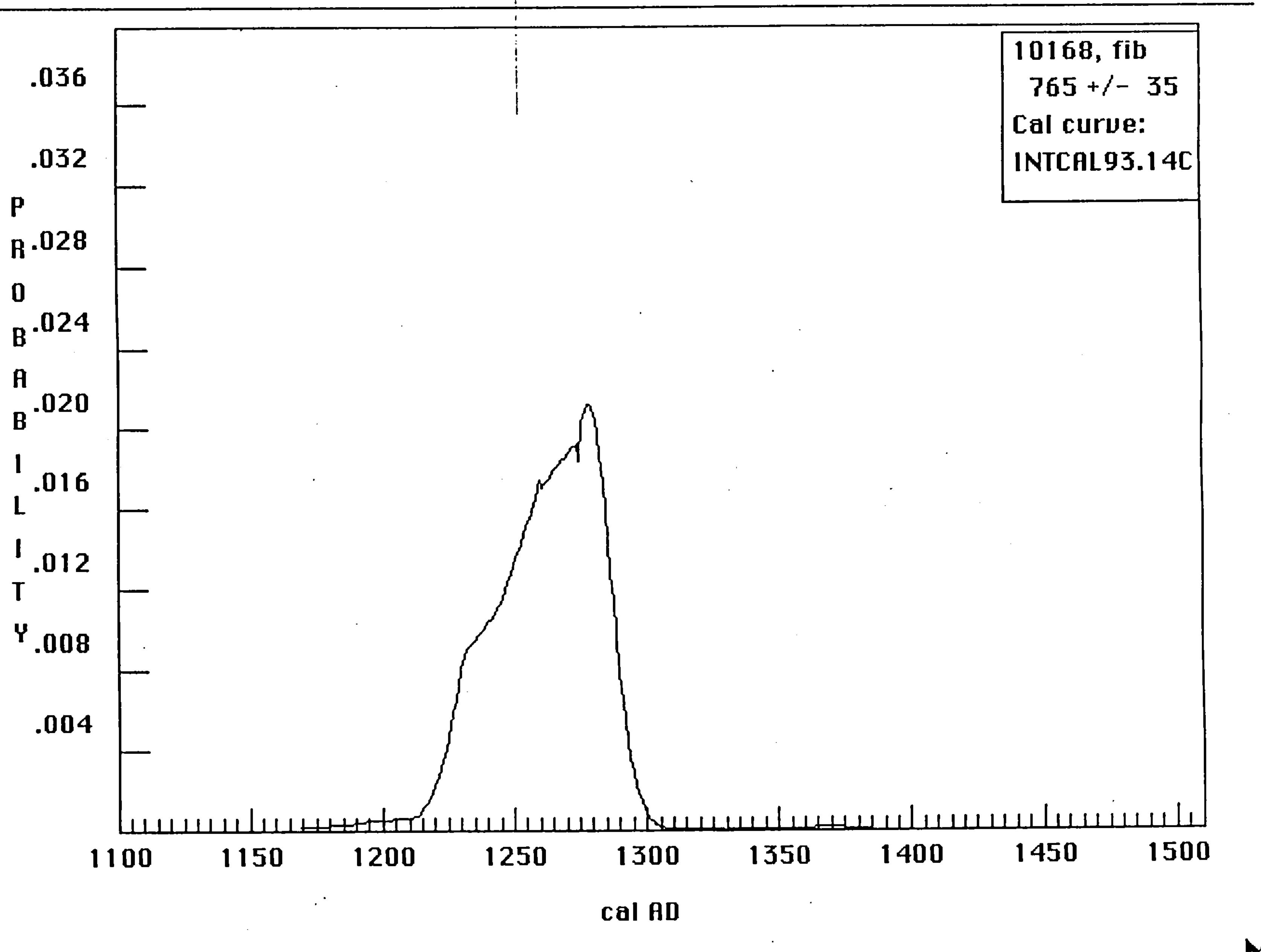
Subject: Oak Island Samples

I have attached plots of the probability distributions for the calendar ages of the samples from Oak Island. As you may know, the observed distributions arise from the uncertainty in the AMS radiocarbon age determination and the shape of the tree-ring calibration curve. I have included a figure showing the radiocarbon age vs. calendar age calibration curve for the time period encompassing the measured age of the wood sample. As you can see from the probability graph, the wood sample that was submitted may have calendar age of approximately 1720, 1825 or 1900 with the latter being the most likely based on the measured radiocarbon age of 75 +/- 30 years. I hope these graphs are helpful and if you have any questions, do not hesitate to call.

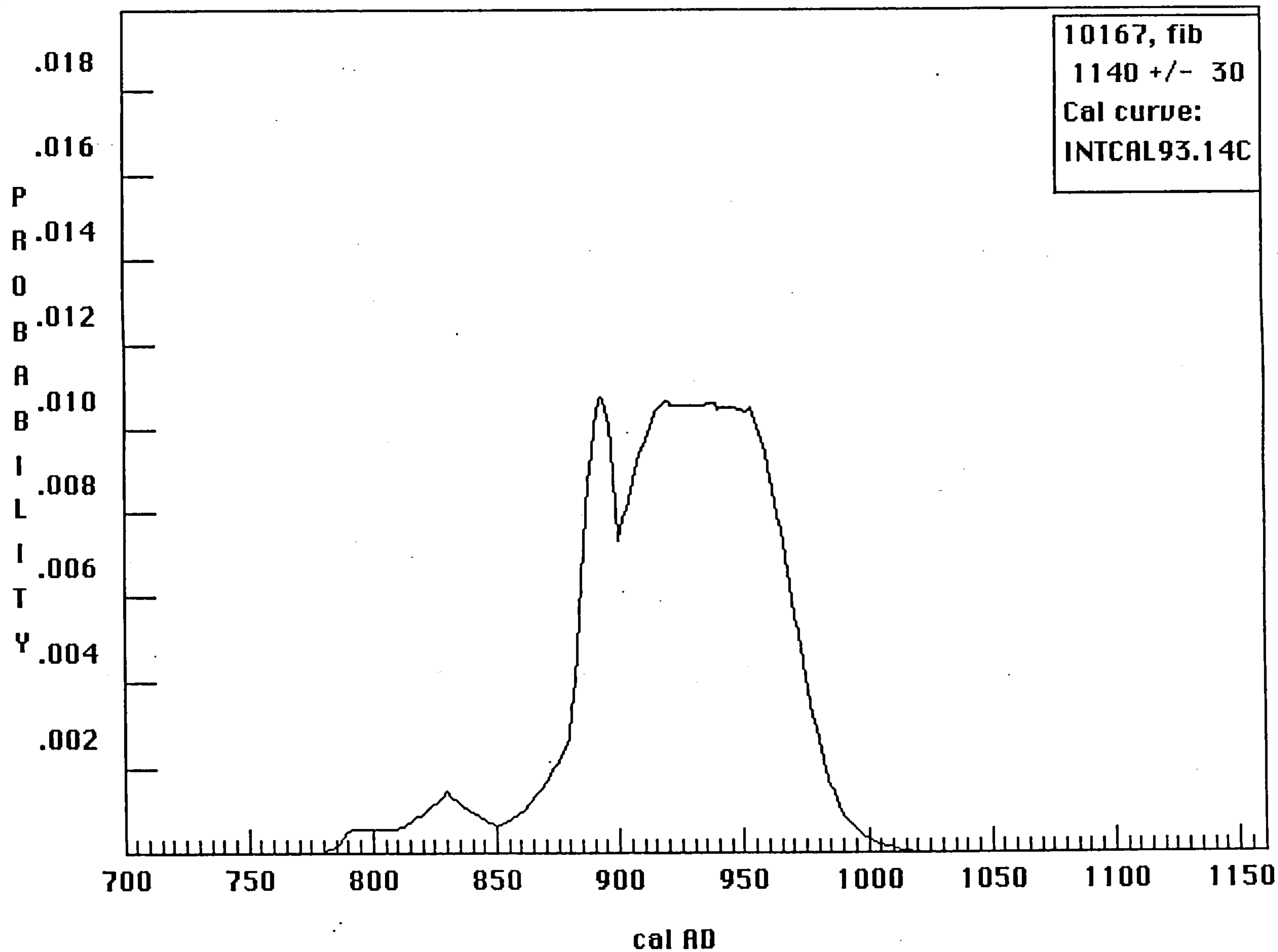
cc: Bob Schneider


WOOD
10166, woo
75 +/- 30
Cal curve:
INTCAL93.14C
PROBABILITY
.018
.016
.014
.012
.010
.008
.006
.004
.002
1600
1650
1700
1750
1800
1850
1900
1950
2000
2050
2100
cal AD

coconut fiber



coconut fiber



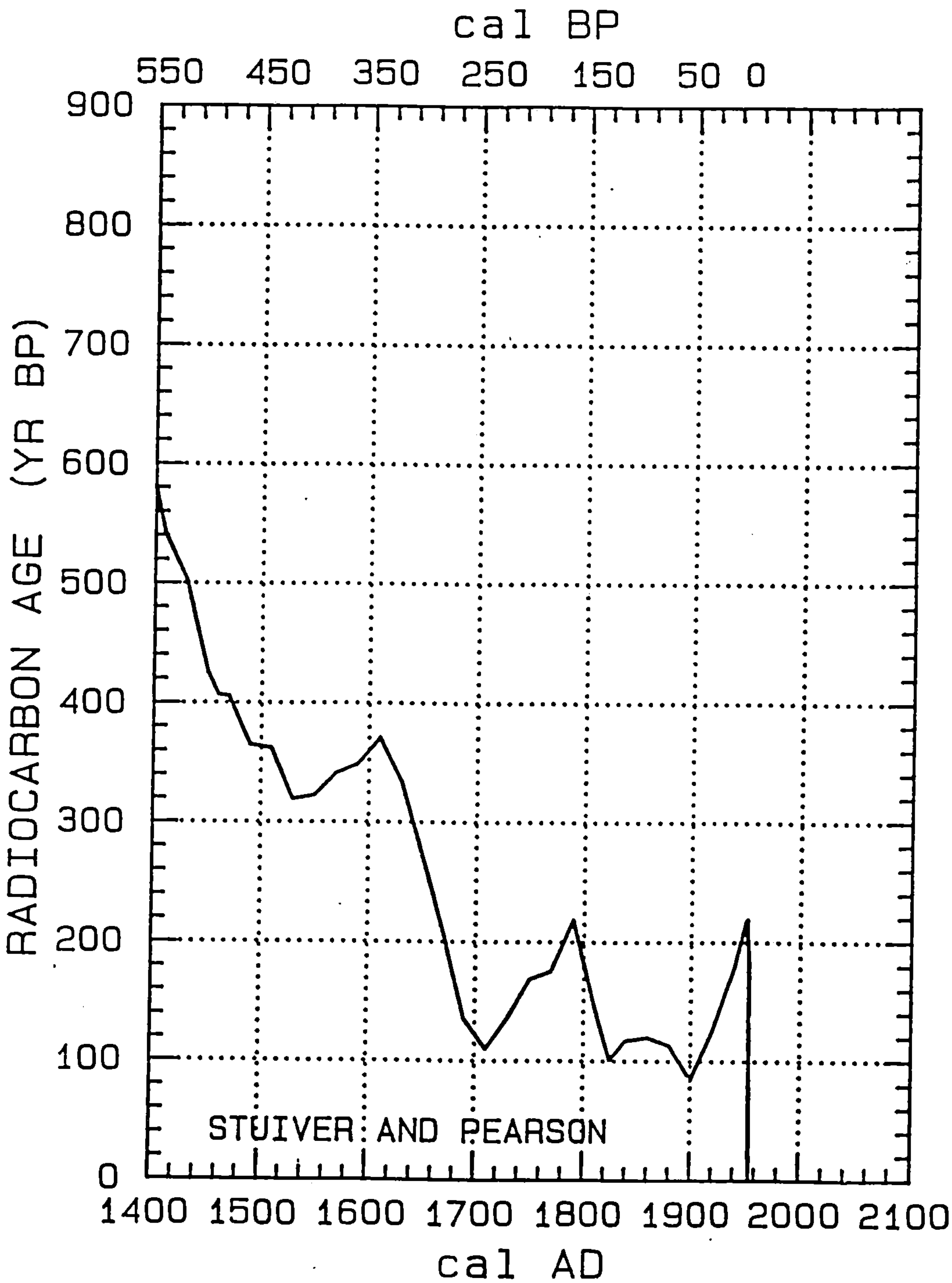
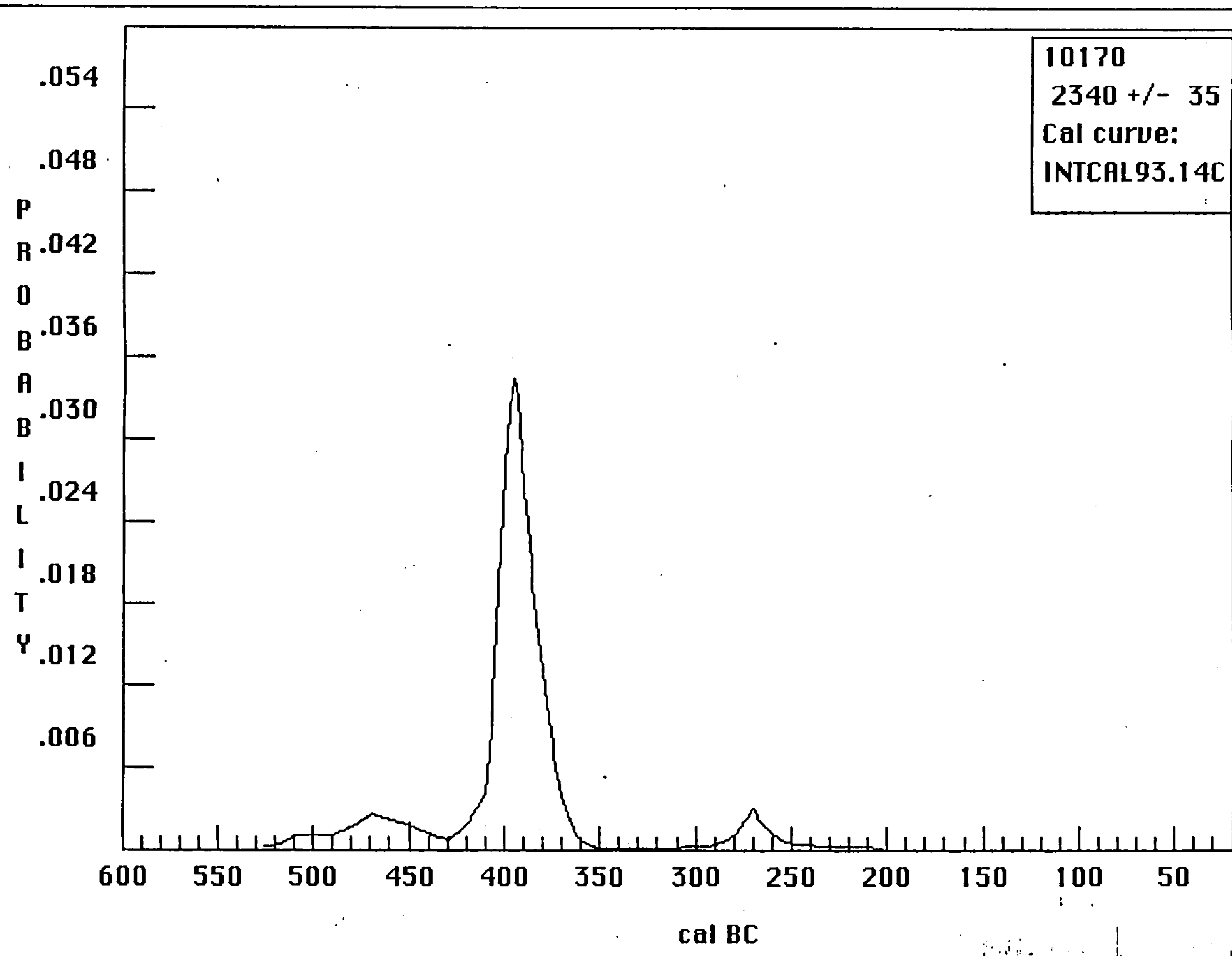


Fig. 1A–L. ^{14}C calibration curve derived from bidecadal samples, with single-year AD 1951–1954 data added to complete the pre-nuclear bomb era

Peat


10170
2340 +/- 35
Cal curve:
INTCAL93.14C
PROBABILITY
.054
.048
.042
.036
.030
.024
.018
.012
.006
600
550
500
450
400
350
300
250
200
150
100
50
cal BC

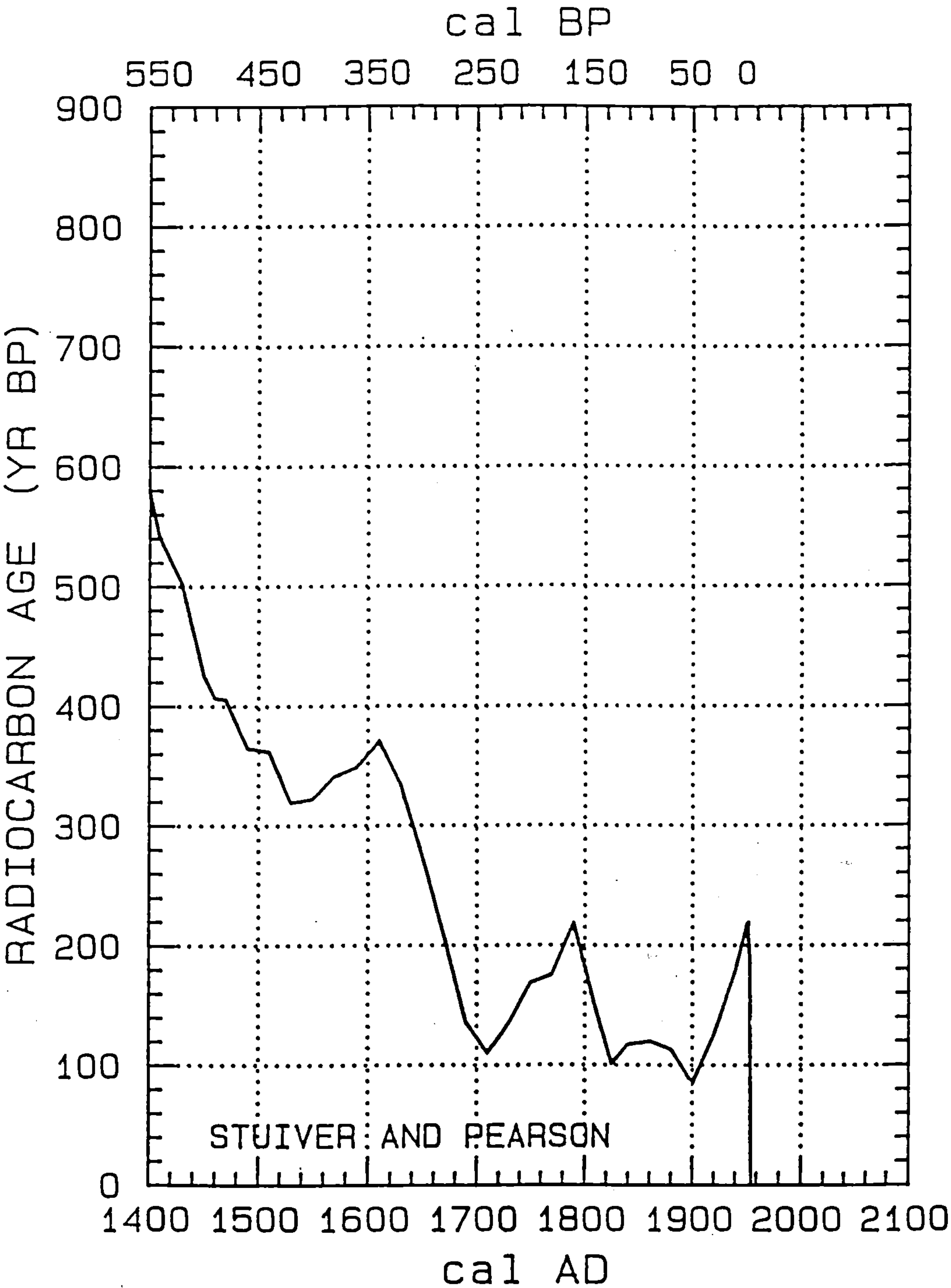


Fig. 1A–L. ^{14}C calibration curve derived from bidecadal samples, with single-year AD 1951–1954 data added to complete the pre-nuclear bomb era

Glenn A. Jones
Director – Ext. 2585

Robert J. Schneider
Assoc. Director – Ext. 2756

Karl F. von Reden
Staff Physicist – Ext. 3384

Ann P. McNichol
Staff Chemist – Ext. 3394

NATIONAL OCEAN SCIENCES AMS FACILITY

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543-1539
Phone: (508) 457-2000 x 2585
Fax: (508) 457-2183

December 7, 1995

REPORT #: 95-103

Dr. David Aubrey
Dept. G&G
Mail Stop 22
W.H.O.I.

Dear Dave,

Please find the enclosed NOSAMS ^{14}C Results Report on 1 of your 7 samples from Oak Island, Nova Scotia. 4 results were previously reported and your remaining 2 are still in progress. There will be no charge for this analysis; it will be considered in-house research. Should you have any questions regarding your results please contact me.

Sincerely,

Robert J. Schneider, Acting Director
National Ocean Sciences AMS Facility

Glenn A. Jones
Director – Ext. 2585

Robert J. Schneider
Assoc. Director – Ext. 2756

Karl F. von Reden
Staff Physicist – Ext. 3384

Ann P. McNichol
Staff Chemist – Ext. 3394

NATIONAL OCEAN SCIENCES AMS FACILITY

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543-1539
Phone: (508) 457-2000 x 2585
Fax: (508) 457-2183

Data Report #95-103

Radiocarbon Results: Dr. David Aubrey/Gutierrez

12/07/95

A.P. McNichol, Radiocarbon Analyst
National Ocean Sciences
AMS Facility

General Statement of ^{14}C Procedures at the National Ocean Sciences AMS Facility

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Stable isotope measurements of sample $\delta^{13}C$ used to correct F_m values are typically made at the NOSAMS Facility by analyzing sub-samples of the CO_2 gas generated during graphite production with either a VG PRISM or VG OPTIMA mass spectrometer. However, most carbonate samples are reacted and measured directly with the VG PRISM ISOCARB. The $\delta^{13}C$ value used to calculate the F_m of a sample is specified in the report of Final Results.

Reporting of ages and/or activities follows the convention outlined by Stuiver and Polach (1977) and Stuiver (1980). Radiocarbon ages are calculated using 5568 (yrs) as the half-life of radiocarbon and are reported without reservoir corrections or calibration to calendar years. For all sea water samples, where collection date is known, or for other samples where the age is known, such as wood from tree rings, live-collected molluscs, or corals, a $\Delta^{14}C$ activity which has been corrected to 1950 values is also reported.

Atoms of ^{14}C contained in a sample are directly counted using the AMS method of radiocarbon analysis, therefore, internal statistical errors are calculated using the number of counts measured from each target. An external error is calculated from the reproducibility of individual analyses for a given target. The error reported is the larger of the internal or external errors.

When reporting AMS results of samples run at the NOSAMS facility, accession numbers (e.g. OS-####'s) are required to be listed together with the results. To avoid confusion, we suggest tabulating OS-numbers and associated radiocarbon ages as they appear on the attached Final Report in addition to any subsequent corrections that may need to be made to the ages. We ask that published results acknowlege support from NSF by including the NSF Cooperative Agreement number, OCE 801015. The NOSAMS facility would appreciate receiving reprints or preprints of papers referencing AMS analyses made at the NOSAMS facility.

Any sample material not consumed during sample preparation or AMS radiocarbon analysis is permanently archived at the NOSAMS Facility unless other arrangements are made by the submitter.

REFERENCES

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Olsson, I.U., 1970. The use of Oxalic acid as a Standard. *In* I.U. Olsson, ed., Radiocarbon Variations and Absolute Chronology, Nobel Symposium, 12th Proc., John Wiley & Sons, New York, p. 17.

Stuiver, M. and Polach, H.A., 1977. Discussion: Reporting of ^{14}C data. Radiocarbon, 19:355-363.

Stuiver, M., 1980. Workshop on ^{14}C data reporting. Radiocarbon, 22:964-966.

Sample Description

Please Note Receipt Numbers

Receipt	Kind	Type	Submitter Type	Submitter ID	Description
10165	Biological	Wood	Oak Island, Nova Scotia	OI-W6	wood

:ceipt	Process	NOSAMS Accession #	$\delta^{13}C$	δ^{13} C Source		F Modern	Fm Error	Age	Age Error
0165	OC	OS-6230	-24.49	NOSAMS	Prism	0.9849	0.0045	120	35

NATIONAL OCEAN SCIENCES AMS FACILITY

Robert J. Schneider
Assoc. Director – Ext. 2756

Karl F. von Reden
Staff Physicist – Ext. 3384

Ann P. McNichol
Staff Chemist – Ext. 3394

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543-1539
Phone: (508) 457-2000 x 2585
Fax: (508) 457-2183

January 11, 1996

REPORT #: 96-005

Dr. David Aubrey
Dept. G&G
Mail Stop 22
W.H.O.I.

Dear Dave,.

Please find the enclosed NOSAMS ^{14}C Results Report on your remaining 2 samples from Oak Island, Nova Scotia. As with the previous 5 results, there will be no charge for these analyses; it will be considered in-house research. Should you have any questions regarding your results please contact me.

Sincerely,

Robert J. Schneider, Acting Director
National Ocean Sciences AMS Facility

General Statement of ^{14}C Procedures
at the National Ocean Sciences AMS Facility

All laboratory preparations for AMS radiocarbon analyses of submitted samples occur in the NOSAMS Sample Preparation Lab unless otherwise noted on the attached report of Final Results. Procedures appropriate to the raw material being analyzed include: acid hydrolysis (HY), combustion (OC), or stripping of CO_2 gas from water (WS) samples. Carbon dioxide, whether submitted (GS) or generated at the NOSAMS Facility, reacted to form graphite using an Fe/H_2 catalytic-reduction. Graphite is pressed into targets which are analyzed on the accelerator along with standards and process blanks. Two primary standards are used during all ^{14}C measurements: NBS Oxalic Acid I (NIST-SRM-4990) and Oxalic Acid II (NIST-SRM-4990C). The ^{14}C activity ratio of Oxalic Acid II ($\delta^{13}C$ = -17.3 per mil) to Oxalic Acid I ($\delta^{13}C$ = -19.0 per mil) is taken to be 1.293. Every group of samples processed includes an appropriate blank which is analyzed concurrently with the group. Process blank materials include IAEA C-1 Carrarra marble for inorganic carbon and gas samples; a Johnson-Mathey 99.9999% graphite powder for organic carbon samples; and a commercial tank of ^{14}C- free CO_2 for seawater samples.

Fraction Modern (F_m) is a measurement of the deviation of the $^{14}C/C$ ratio of a sample from "modern." Modern is defined as 95% of the radiocarbon concentration (in AD 1950) of NBS Oxalic Acid I normalized to $\delta^{13}C_{VPDB}$ = -19 per mil (Olsson, 1970). AMS results are calculated using the internationally accepted modern value of 1.176 ±0.010 x 10^{-12} (Karlen, *et. al.*, 1968) and a final ^{13}C-correction is made to normalize the sample F_m to a $\delta^{13}C_{VPDB}$ value of -25 per mil.

Stable isotope measurements of sample $\delta^{13}C$ used to correct F_m values are typically made at the NOSAMS Facility by analyzing sub-samples of the CO_2 gas generated during graphite production with either a VG PRISM or VG OPTIMA mass spectrometer. However, most carbonate samples are reacted and measured directly with the VG PRISM ISOCARB. The $\delta^{13}C$ value used to calculate the F_m of a sample is specified in the report of Final Results.

Reporting of ages and/or activities follows the convention outlined by Stuiver and Polach (1977) and Stuiver (1980). Radiocarbon ages are calculated using 5568 (yrs) as the half-life of radiocarbon and are reported without reservoir corrections or calibration to calendar years. For all sea water samples, where collection date is known, or for other samples where the age is known, such as wood from tree rings, live-collected molluscs, or corals, a $\Delta^{14}C$ activity which has been corrected to 1950 values is also reported.

Atoms of ^{14}C contained in a sample are directly counted using the AMS method of radiocarbon analysis, therefore, internal statistical errors are calculated using the number of counts measured from each target. An external error is calculated from the reproducibility of individual analyses for a given target. The error reported is the larger of the internal or external errors.

When reporting AMS results of samples run at the NOSAMS facility, accession numbers (e.g. OS-####'s) are required to be listed together with the results. To avoid confusion, we suggest tabulating OS-numbers and associated radiocarbon ages as they appear on the attached Final Report in addition to any subsequent corrections that may need to be made to the ages. We ask that published results acknowlege support from NSF by including the NSF Cooperative Agreement number, OCE 801015. The NOSAMS facility would appreciate receiving reprints or preprints of papers referencing AMS analyses made at the NOSAMS facility.

Any sample material not consumed during sample preparation or AMS radiocarbon analysis is permanently archived at the NOSAMS Facility unless other arrangements are made by the submitter.

REFERENCES

Karlen, I., Olsson, I.U., Kallburg, P. and Kilici, S., 1968. Absolute determination of the activity of two ^{14}C dating standards. Arkiv Geofysik, 4:465-471.

Olsson, I.U., 1970. The use of Oxalic acid as a Standard. *In* I.U. Olsson, ed., Radiocarbon Variations and Absolute Chronology, Nobel Symposium, 12th Proc., John Wiley & Sons, New York, p. 17.

Stuiver, M. and Polach, H.A., 1977. Discussion: Reporting of ^{14}C data. Radiocarbon, 19:355-363.

Stuiver, M., 1980. Workshop on ^{14}C data reporting. Radiocarbon, 22:964-966.

Sample Description

Please Note Receipt Numbers

Receipt	Kind	Type	Submitter Type	Submitter ID	Description
10164	Biological	Plant	Oak Island, Nova Scotia	OI-ICFI	seaweed
10169	Biological	Plant	Oak Island, Nova Scotia	OI-BP-2	peat

Receipt	Process	NOSAMS Accession #	$\delta^{13}C$	$\delta^{13}C$ Source		F Modern	Fm Error	Age	Age Error
10164	OC	OS-6443	-20.11	NOSAMS	Prism	1.0580	0.0031	>Mod.	
10169	OC	OS-6437	-28.19	NOSAMS	Prism	0.7855	0.0037	1940	40

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(305) 665-2844
Fax: (305) 665-8032

9 Jan 1996

Mr. Ben Gutierrez
Woods Hole Oceanographic Institute
360 Woods Hole Rd. MS 22
Woods Hole, MA 02543

Dear Ben,

I've finally had a chance to look at the specimen of fiber, which I am returning to you, along with the SEM photos, in this envelope. I'm afraid I can't be of much help. The fibers don't look like palm leaf-base fibers (such as one sees on *Coccothrinax*) to me in that they are in more or less parallel groups. Could they be stem fibers with the ground tissue decayed? Possibly, but your letter indicated that you didn't think the fibers had been in an anaerobic deposit, hence decay would have been less likely. Could they be fruit fibers, such as the husk fibers of a coconut? Maybe, although my light-microscope comparison with modern fibers are inconclusive. I'm enclosing a small sample of coconut husk fiber from a specimen in our herbarium (*Hull H-32*). You may wish to make SEM photos or try retting away the ground tissue to see how the fibers look.

Sorry I couldn't be of more help. It's an interesting find. Please let me know what you conclude.

Best wishes,

Scott Zona
Palm Biologist
zonas@servax.fiu.edu

From nwul@cornell.edu Thu Dec 14 15:23:35 1995
Return-Path: <nwul@cornell.edu>
Received: from postoffice.mail.cornell.edu ([132.236.56.7]) by mud.whoi.edu (4.1/SMI-4.1)
id AA06231; Thu, 14 Dec 95 15:23:33 EST
Received: from postoffice.mail.cornell.edu ([128.253.177.15]) by postoffice.mail.cornell.edu
Date: Thu, 14 Dec 1995 15:16:39 -0500
Message-Id: <199512142016.PAA03679@postoffice.mail.cornell.edu>
X-Sender: nwul@postoffice.mail.cornell.edu
X-Mailer: Windows Eudora Version 2.0.3
Mime-Version: 1.0
Content-Type: text/plain; charset="us-ascii"
To: ben@mud.whoi.edu
From: nwul@cornell.edu (Natalie Uhl)
Subject: Specimens
Status: R

Dear Dr. Gutierrez,

We have had a look at the material you sent. The SEM photos of the transections of the fibers do closely resemble the configuration of the fibrous bundle sheaths in some palm stems. It is not possible to say definitely that these are palms just that they could be. It would help to have all of the bundle, i.e., the xylem to check on what sort of vessels might be present. We might then be able to state more strongly that the material is from a palm Regretably I don't believe there is any way to identify the material to genus and species. As I told you by phone Francisco Guanchez is here from Venezuela. He is working on Leopoldinia, a genus that has long been exploited for fiber. We expect in March to look into the anatomy of fibers in that and several other other palms, We could examine the material you sent a little more closely at that time, unless you would like the specimens returned before then. Sincerely, Natalie Uhl