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ACOUSTIC IMPEDANCE OF SEA WATER AS A FUNCTION OF TEMPERATURE, PRESSURE AND SALINITY

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ACOUSTIC IMPEDANCE OF SEA WATER AS A FUNCTION OF TEMPERATURE, PRESSURE AND SALINITY

by

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ABSTRACT: The acoustic impedance (ρc) of sea water is presented as a function of temperature, pressure and salinity. This acoustic impedance has been calculated from empirical equations developed at the Naval Ordnance Laboratory to represent the velocity of sound and density of sea water as functions of the parameters temperature, pressure, and salinity. Tables of the calculated data and graphs are given.

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Information on the acoustic properties of sea water is of continuing interest to the U. S. Navy. In anticipation of the future needs of the Fleet, information has been obtained on the extremes of temperature, pressure and salinity and various related acoustic properties likely to be needed in naval applications. The present work was funded under FR-27, "Structure of Liquids". This information will be useful to anyone computing the transmission properties of acoustic waves in sea water.

J. DARE
Captain, USN
Commander

Z. I. SLAWSKY
By direction

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INTRODUCTION

The characteristic impedance of a medium for acoustic waves(1) is analogous to the index of refraction (n) of a transparent medium for light waves and to the wave impedance $\sqrt{\frac{\mu}{\epsilon}}$ of a dielectric medium for electromagnetic waves. The product of the velocity of sound (c) and the density (ρ) provides a measurement of this characteristic impedance and is useful in the investigation of transmission phenomena of acoustic plane waves.

The results presented in this report were obtained from two empirical equations based on precision data taken at NOL. The first(2) represents sound velocity in sea water as a function of the three parameters: temperature, pressure and salinity. The second equation(3) represents the specific volume of sea water as a function of the same parameters. Both equations were developed to represent experimental data obtained from laboratory measurements. The product of the two, ($c \times 1/v$), provides the acoustic impedance. The impedance data was calculated for the following parameter ranges: Temperature: $0^\circ C < T < 30^\circ C$, pressure: $1 \text{ bar} < P < 1000 \text{ bars}$, salinity: $0‰ < S < 37‰$. The bar as used in this report means 10^6 dyne/cm^2.

THEORY

To avoid confusion, a brief summary of the various impedance terms is given. There are three kinds of acoustic impedances in common usage. First, the ratio of pressure to volume velocity, $\bar{Z}$ which is useful in discussing acoustic radiation from vibrating surfaces, and the transmission of this radiation through lumped acoustic elements at low frequencies. Second, the radiation impedance $\bar{Z}_r$, the ratio of force to velocity, is useful in calculating the coupling between acoustic waves and a driving source or driven load. It is part of the mechanical impedance of a vibrating system associated with the radiation of sound. Last, the specific acoustic impedance, is a characteristic property of the medium and of the type of waves that are being propagated through it. By definition, the complex ratio of acoustic pressure ($\vec{p}$) in a medium to the associated particle velocity ($\vec{u}$) is the <u>specific acoustic impedance</u>. In general

$$\vec{Z} = \frac{\vec{p}}{\vec{u}} = r + jx,$$

where $\vec{Z}$ = is a complex quantity. The term r is called the <u>specific acoustic resistance</u> and x the <u>specific acoustic reactance</u> of the medium for the particular wave motion being considered.

EQUATIONS

The equations representing the sound velocity and specific volume in sea water are empirical equations which were fitted to the laboratory experimental data. The coefficients of the equations were obtained by making a least squares fit to the experimental data on an IBM 7090 computer. Equation (1) can be used to calculate the sound velocity and Equation (2) the specific volume.

$$\begin{aligned}
C = {} & 1449.14 + 4.5721\ T - 4.4532 \times 10^{-2}T^{2} - 2.6045 \times 10^{-4}T^{3} \\
& + 7.9851 \times 10^{-6}T^{4} + 1.63431 \times 10^{-1}P + 1.0677 \times 10^{-5}P^{2} \\
& + 3.7340 \times 10^{-9}P^{-3} - 3.6332 \times 10^{-12}P^{4} + 1.39799\ (S-35.0) \\
& + 1.69202 \times 10^{-3}\ (S-35.0)^{2} + (S-35.0)\ (-1.1244 \times 10^{-2}T \\
& + 7.7711 \times 10^{-7}T^{2} + 7.8534 \times 10^{-5}P - 1.3458 \times 10^{-7}P^{2} \\
& + 3.2202 \times 10^{-8}PT + 1.6101 \times 10^{-9}PT^{2}) + 1.01971\ P \\
& (-1.8607 \times 10^{-4}T + 7.4812 \times 10^{-6}T^{2} + 4.5283 \times 10^{-8}T^{3}) \\
& + 1.03981\ P^{2}\ (-2.5294 \times 10^{-7}T + 1.8563 \times 10^{-9}T^{2}) \\
& + 1.06030\ P^{3}\ (-1.9646 \times 10^{-10}T)
\end{aligned} \qquad (1)$$

$$v = 0.7020 + \frac{1752.7286 + 11.001055T - 0.0639125T^{2} - (3.9986175 + 0.010731021T)S}{P + 5880.9069 + 37.591888T - 0.343935T^{2} + 2.2524542S} \qquad (2)$$

The units of the various parameters are: Specific volume (cm^3/gm), sound velocity (m/sec), temperature (°C), pressure (bars) and salinity (‰).

The standard deviations were computed from the expression

$$\sigma = \sqrt{\frac{\sum_{n=1}^{N} (x_e - x_c)^2}{N - k}} \qquad (3)$$

where x_e and x_c are experimental and calculated data points respectively, N is the total number of data points and k the number of coefficients in the representative equation. For Equation (1) $\sigma = 0.30$ m/sec and for Equation (2) $\sigma = 0.00013$ cm^3/gm. These standard deviations show how well the empirical equations fit the experimental data. The equations are very convenient for machine computations since they provide analytic expressions for the data.

RESULTS

The results from the computations are shown in Tables I to V and also are presented graphically in Figs. 1 to 4.

REFERENCES

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2. W. Wilson, J. Acoust. Soc. Am., 32, 1357 (1960).
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TABLE I

Salinity = 0°/oo

Acoustic Impedance (gm/cm^2·sec)

P \ T	0°C	10°C	20°C	30°C
1 bar	$1.402\mathrm{x}10^{+5}$	$1.447\mathrm{x}10^{+5}$	$1.480\mathrm{x}10^{+5}$	$1.504\mathrm{x}10^{+5}$
100 "	1.426	1.470	1.503	1.527
200 "	1.449	1.493	1.526	1.550
300 "	1.473	1.517	1.550	1.574
400 "	1.498	1.540	1.573	1.597
500 "	1.522	1.564	1.597	1.621
600 "	1.547	1.589	1.621	1.644
700 "	1.572	1.613	1.644	1.668
800 "	1.598	1.638	1.668	1.691
900 "	1.624	1.662	1.692	1.715
1000 "	1.650	1.687	1.716	1.737

TABLE II

Salinity = 10°/oo

Acoustic Impedance (gm/cm^{2}·sec)

T P	0°C	10°C	20°C	30°C
1 bar	1.427x10^{+5}	1.470x10^{+5}	1.502x10^{+5}	1.525x10^{+5}
100 "	1.450	1.493	1.525	1.548
200 "	1.474	1.516	1.549	1.572
300 "	1.498	1.540	1.572	1.595
400 "	1.522	1.564	1.596	1.619
500 "	1.547	1.588	1.619	1.642
600 "	1.572	1.612	1.643	1.666
700 "	1.597	1.637	1.667	1.689
800 "	1.623	1.661	1.691	1.713
900 "	1.648	1.686	1.714	1.736
1000 "	1.674	1.710	1.738	1.758

TABLE III

Salinity = $20^{\circ}/oo$

Acoustic Impedance ($gm/cm^2 \cdot sec$)

P \ T	0°C	10°C	20°C	30°C
1 bar	$1.452\times10^{+5}$	$1.494\times10^{+5}$	$1.525\times10^{+5}$	$1.547\times10^{+5}$
100 "	1.475	1.517	1.548	1.570
200 "	1.499	1.540	1.571	1.593
300 "	1.523	1.564	1.595	1.617
400 "	1.548	1.588	1.618	1.640
500 "	1.572	1.612	1.642	1.664
600 "	1.597	1.636	1.666	1.688
700 "	1.623	1.661	1.690	1.711
800 "	1.648	1.685	1.714	1.734
900 "	1.674	1.710	1.737	1.757
1000 "	1.700	1.734	1.760	1.780

TABLE IV

Salinity = $30^{o}/oo$

Acoustic Impedance ($gm/cm^{2}\cdot sec$)

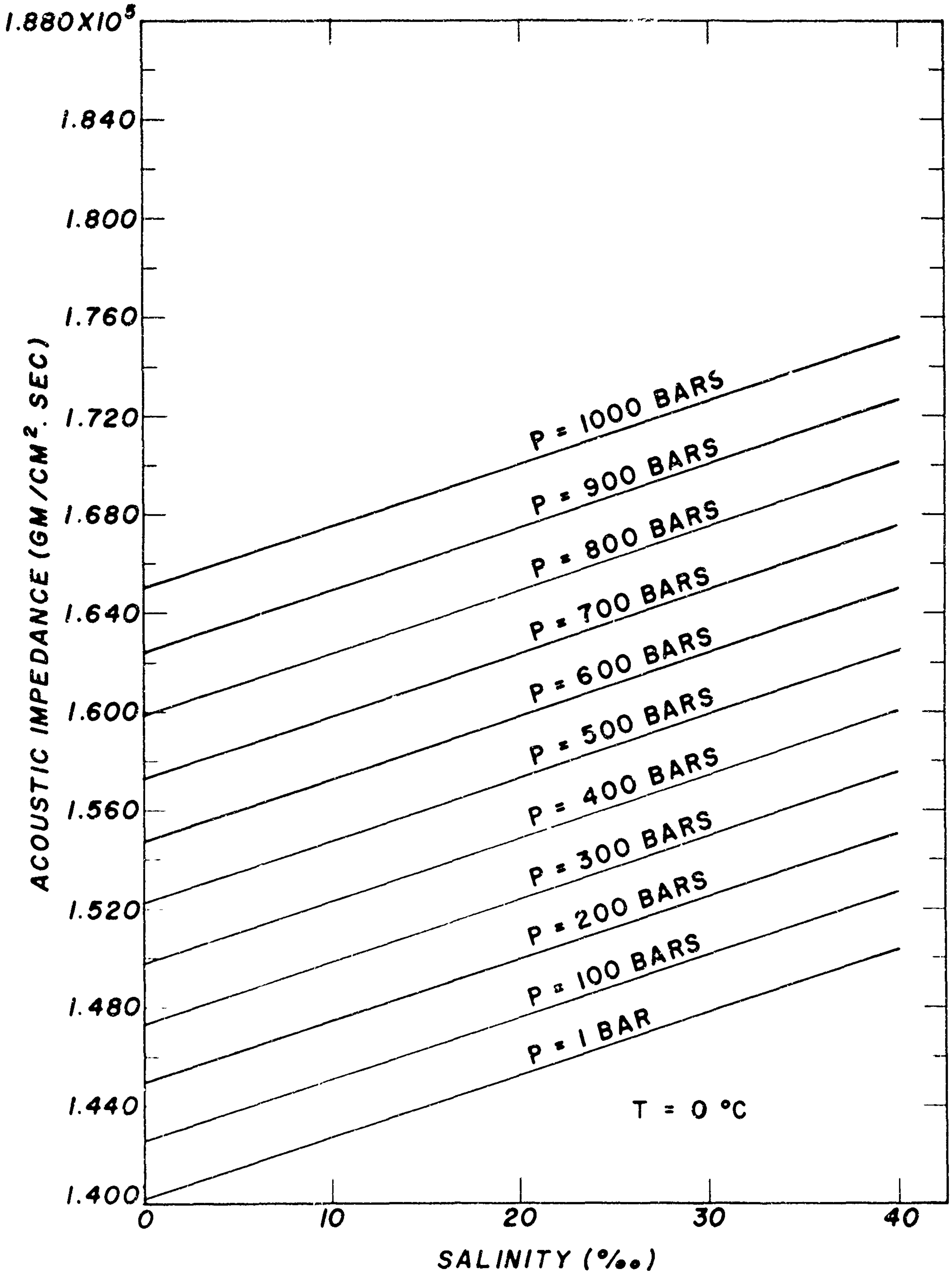
T P	$0^{o}C$	$10^{o}C$	$20^{o}C$	$30^{o}C$
1 bar	$1.477\mathrm{x}10^{+5}$	$1.518\mathrm{x}10^{+5}$	$1.548\mathrm{x}10^{+5}$	$1.569\mathrm{x}10^{+5}$
100 "	1.501	1.541	1.571	1.592
200 "	1.525	1.565	1.595	1.616
300 "	1.549	1.589	1.618	1.639
400 "	1.574	1.613	1.642	1.663
500 "	1.598	1.637	1.666	1.686
600 "	1.623	1.661	1.690	1.710
700 "	1.649	1.686	1.713	1.734
800 "	1.674	1.710	1.737	1.757
900 "	1.700	1.734	1.760	1.780
1000 "	1.725	1.759	1.784	1.802

TABLE V

Salinity = 35°/oo

Acoustic Impedance (gm/cm^2·sec)

P \ T	0°C	10°C	20°C	30°C
1 bar	$1.490\times10^{+5}$	$1.531\times10^{+5}$	$1.560\times10^{+5}$	$1.580\times10^{+5}$
100 "	1.514	1.554	1.583	1.603
200 "	1.538	1.578	1.607	1.627
300 "	1.562	1.601	1.630	1.651
400 "	1.587	1.626	1.654	1.674
500 "	1.612	1.650	1.678	1.698
600 "	1.637	1.674	1.702	1.722
700 "	1.662	1.698	1.725	1.745
800 "	1.687	1.723	1.749	1.768
900 "	1.713	1.747	1.772	1.791
1000 "	1.739	1.771	1.796	1.813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1.760
1.720
1.680
1.640
1.600
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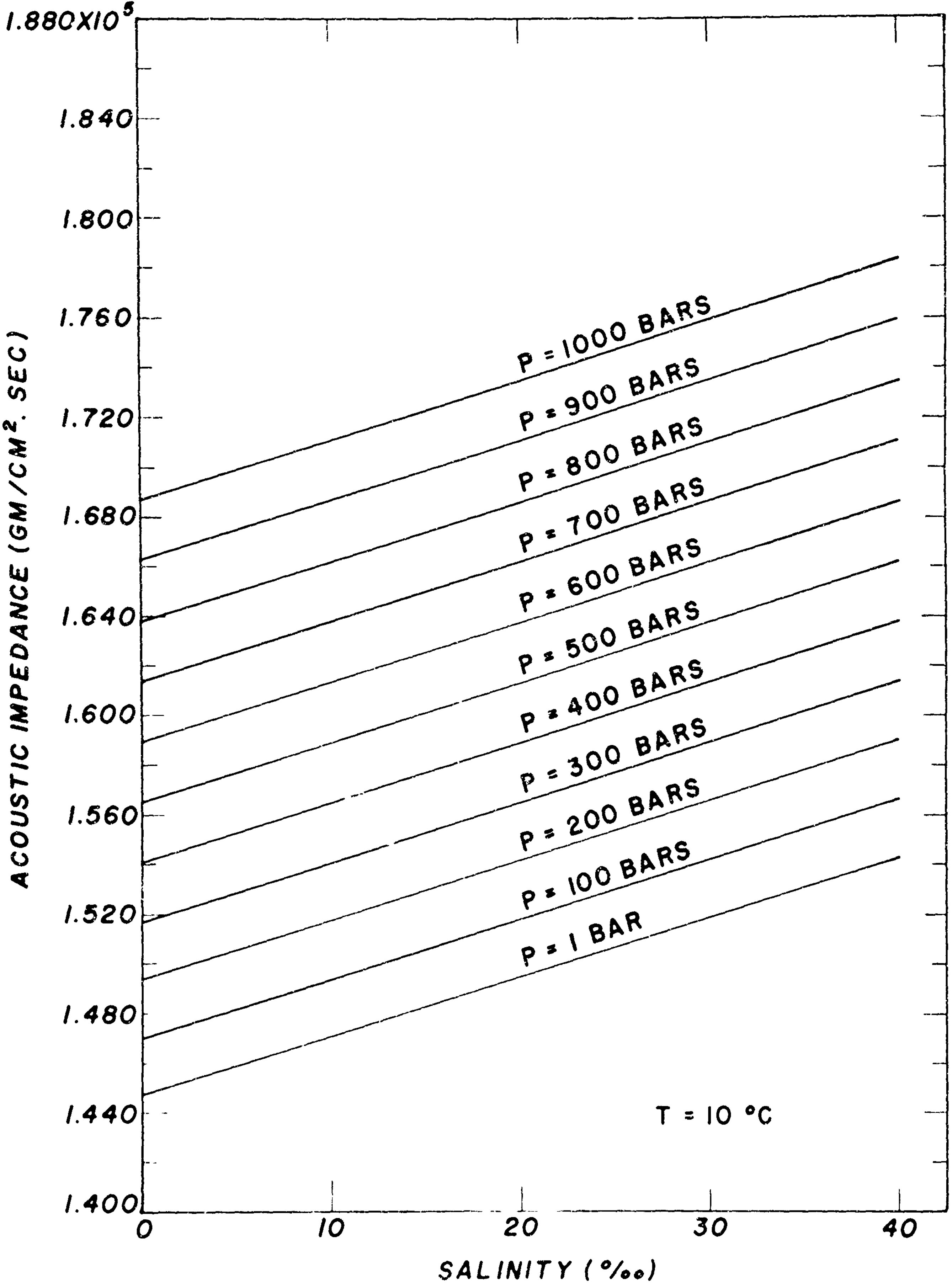
1.520
1.480
1.440
1.400
ACOUSTIC IMPEDANCE (GM/CM². SEC)
P = 1000 BARS
P = 900 BARS
P = 800 BARS
P = 700 BARS
P = 600 BARS
P = 500 BARS
P = 400 BARS
P = 300 BARS
P = 200 BARS
P = 100 BARS
P = 1 BAR
T = 0 °C
0
10
20
30
40
SALINITY (‰)

FIG. 1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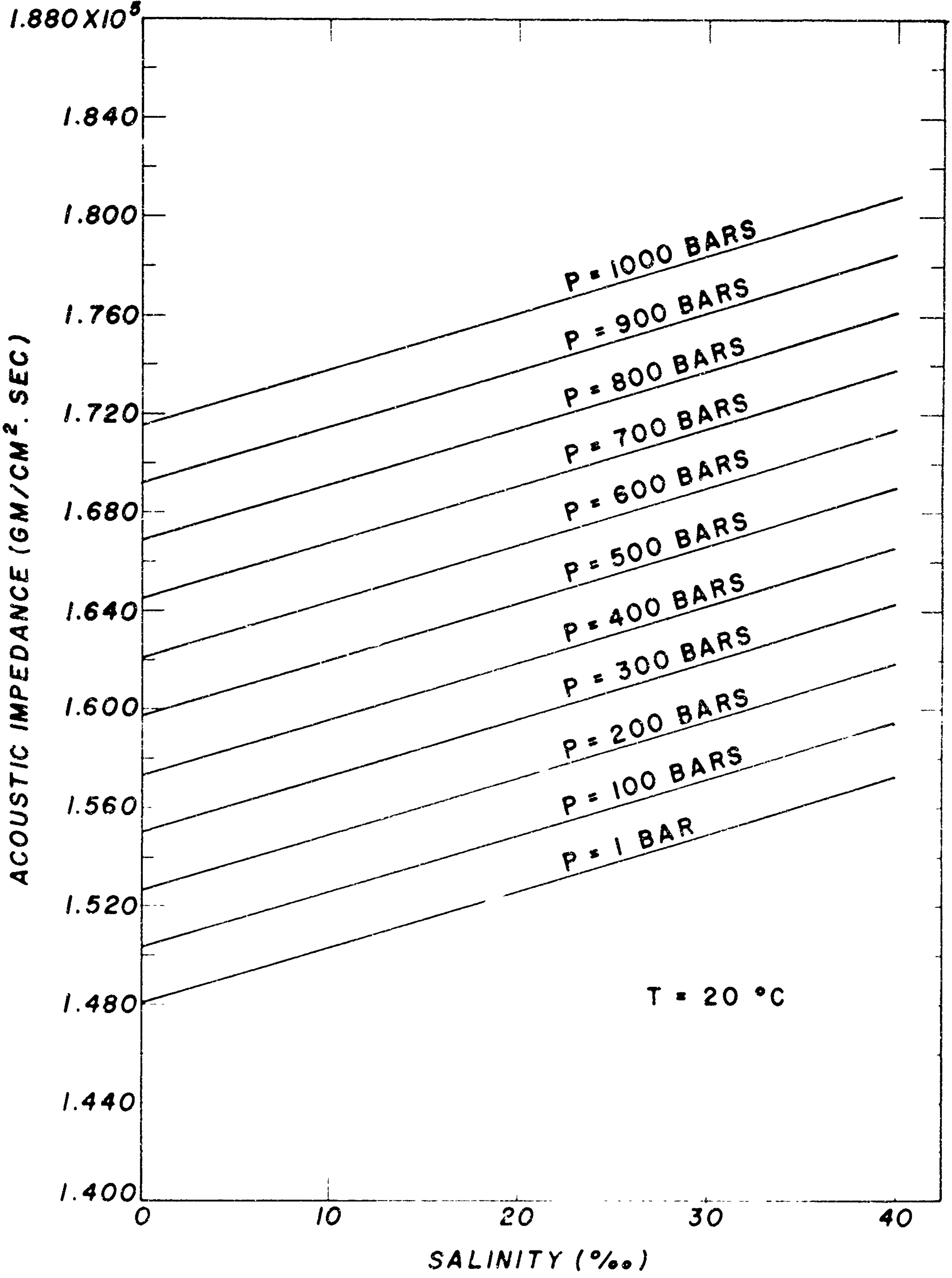
1.400
ACOUSTIC IMPEDANCE (GM/CM^2. SEC)
P = 1000 BARS
P = 900 BARS
P = 800 BARS
P = 700 BARS
P = 600 BARS
P = 500 BARS
P = 400 BARS
P = 300 BARS
P = 200 BARS
P = 100 BARS
P = 1 BAR
T = 10 °C
0
10
20
30
40
SALINITY (°/oo)

FIG. 2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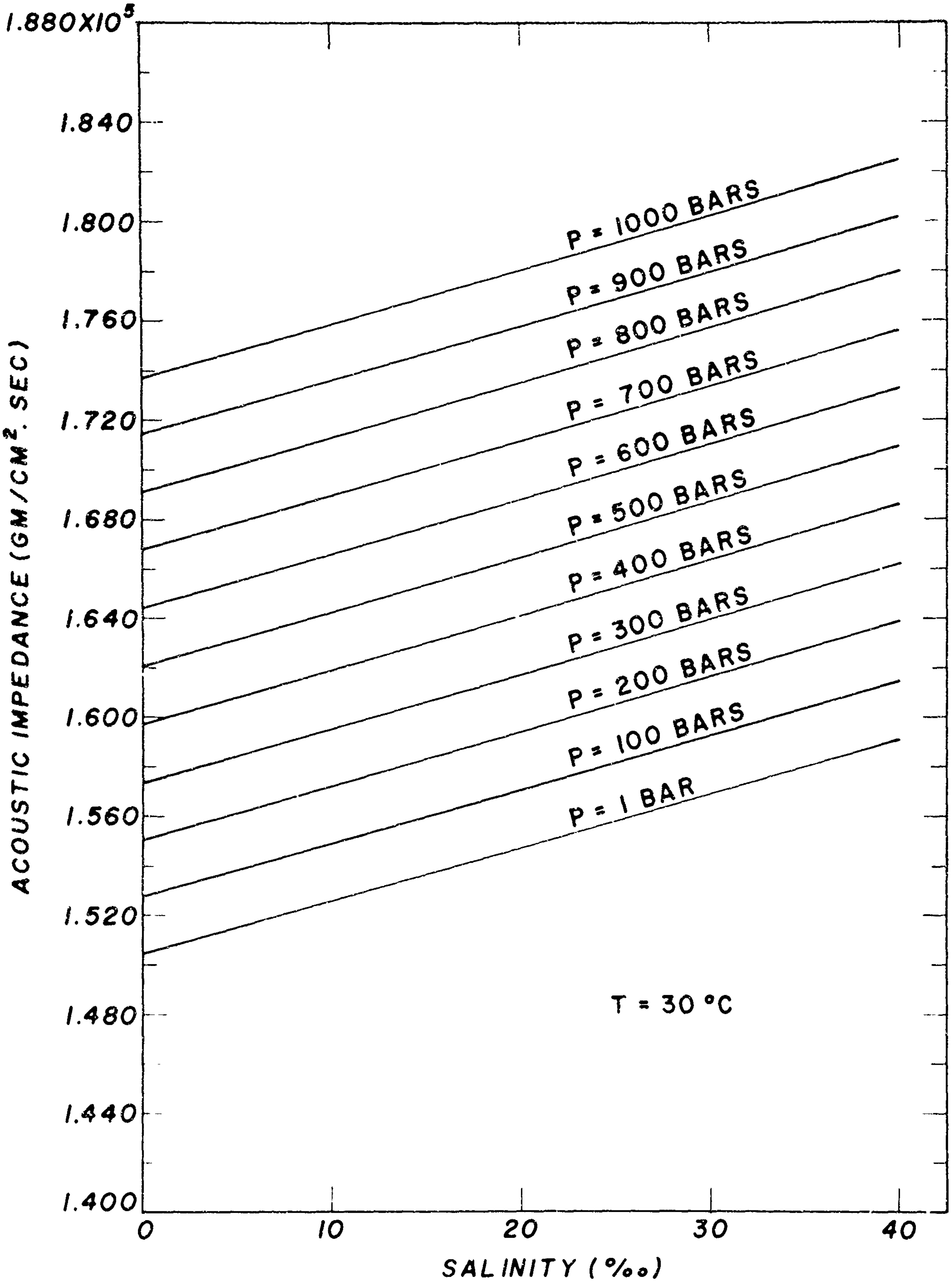
1.760
1.720
1.680
1.640
1.600
1.560
1.520
1.480
1.440
1.400
ACOUSTIC IMPEDANCE (GM/CM². SEC)
P = 1000 BARS
P = 900 BARS
P = 800 BARS
P = 700 BARS
P = 600 BARS
P = 500 BARS
P = 400 BARS
P = 300 BARS
P = 200 BARS
P = 100 BARS
P = 1 BAR
T = 20 °C
0
10
20
30
40
SALINITY (‰)

FIG 3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1.560
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1.480
1.440
1.400
ACOUSTIC IMPEDANCE (GM/CM^2. SEC)
P = 1000 BARS
P = 900 BARS
P = 800 BARS
P = 700 BARS
P = 600 BARS
P = 500 BARS
P = 400 BARS
P = 300 BARS
P = 200 BARS
P = 100 BARS
P = 1 BAR
T = 30 °C
0
10
20
30
40
SALINITY (‰)

FIG. 4

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13 ABSTRACT

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