

Small Scale Features of Sound Velocity Structure in the Northern Arabian Sea during February - May 1974

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Microstructure of sound velocity in the upper 500 m of the northern Arabian Sea based on STD (salinity-temperature-depth profiler) data is presented. Relatively warm and saline waters of the Persian Gulf intruding into the Arabian Sea at intermediate depths (200-400 m), influence the sound velocity structure and cause formation of an upper sound channel in the northern Arabian Sea. The Persian Gulf waters spread as tongues at 1 or 2 more levels (up to a limited extent), besides the prominent one characterised by temperature inversion and salinity maximum, causing significant perturbations in sound velocity. As the distance from the source region increases, the Persian Gulf water loses its identity and does not affect the sound velocity structure. In the upper 50 m, the sound velocity structure changes significantly from spring to summer during which period a seasonal thermocline forms due to intense surface heating. The studies indicate a seasonal variation in the flow paths of the Persian Gulf water and consequent changes in the sound velocity structure.

Studies on sound propagation in the ocean are useful to understand the physical processes. Velocity of sound in the sea varies with temperature, salinity and pressure. Gas bubbles and sediment particles may also affect the velocity, but these effects are generally small and rare, except near the surface or bottom.

The region under study is specially significant because relatively warm and saline waters from the Persian Gulf intrude into the Arabian Sea at intermediate depths. The Persian Gulf is located in a region characterised by arid climate where evaporation from water surface greatly exceeds the fresh water ingress. Water from the Arabian Sea moves into the Persian Gulf in the surface layers, gets more saline, sinks and passes out through the straits of Hormuz, being replaced by lighter water flowing in over it¹.

Studies on the distribution of sound velocity in the Arabian Sea are quite meagre²⁻⁴. Of particular interest to the present study are those of Fenner and Bucca³, Seshagiri Rao and Sundararamam⁴. These studies are based on data computed from the temperature and salinity values at discrete depths obtained from the Nansen cast. Recent studies using salinity-temperature-depth profiler (STD) have shown that the vertical profiles of these parameters are not smooth, as usually deduced from Nansen cast data, but exhibit a number of both regular and irregular nearly homogeneous layers with typical thicknesses of the order of a few meters or less separated by interfacial regions or transition zones where large gradients are present⁵. This highlights the need for employing temperature and salinity data deduced from

continuous profiles for detailed studies on sound velocity structure, especially in the regions where different water masses are encountered.

Materials and Methods

The present study is based on data⁶ collected employing a self-recording Bisset-Berman STD graphic profiler, with accuracies of $\pm 0.1^\circ\text{C}$, $\pm 0.05\text{‰}$ and $\pm 5\text{ m}$ for temperature, salinity and depth respectively, at 78 stations spread over several sections (Fig. 1) during February - May 1974 under the Oceanographic Expedition on board *INS Darshak*.

Temperature and salinity values deduced from the STD records for every 10 m depth interval up to 500 m have been used as input values for computing sound velocities using Wilson's formula⁷

$$V = 1449.14 + V_t + V_p + V_s + V_{stp}$$

where V represents sound velocity, V_t , V_s , V_p and V_{stp} are the correction terms representing respectively the effects of temperature, salinity and pressure on sound velocity and the combined effect of these 3 parameters on sound velocity.

The depth data have been converted into pressure data using the relation $P = h \rho g$, where h is the depth of water column, ρ mean density and g acceleration due to gravity.

The pressure at the surface (equivalent to the atmospheric pressure) has been added in order to obtain the actual pressure at each depth. The average values of temperature and salinity for a vertical

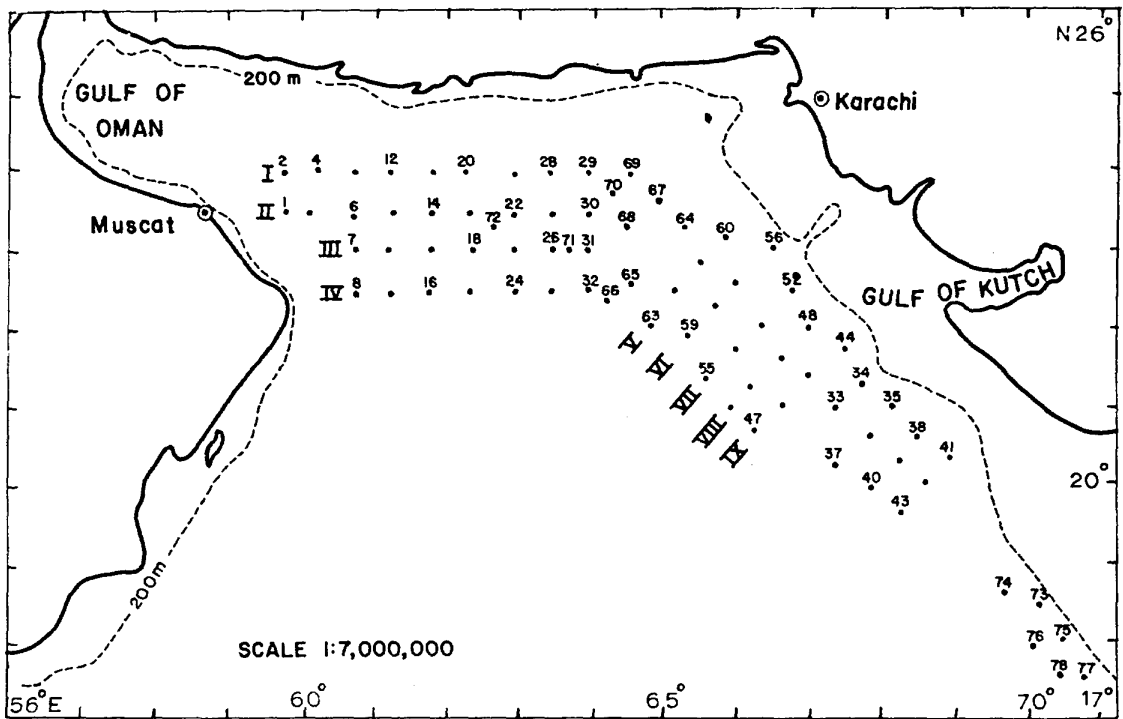


Fig. 1—Location of stations and sections

water column of 500 m in the region under study (20°C and 36‰) have been used to obtain the mean density. The value of g is taken for 22°N (978.818 cm/sec^2). Correction terms in Wilson's equation, V_s , V_i , V_p and V_{sp} are computed from the known temperature, salinity and pressure values and the sound velocities determined. A DCM micro system (Model 1101) has been used for computations.

Vertical profiles of sound velocity for the 4 zonal sections (Fig. 2) and 5 diagonal sections (Fig. 3) have been prepared. The vertical scale is 1100 times the horizontal scale. The isovels are drawn at intervals of 1 m. Wherever the analysis is extended to regions in which the data are incomplete isovels are shown in dash-dot lines. Depth of the axis of the sound channel is shown by a thick line and the boundaries of the channel are shown by dashed lines.

Subsurface salinity and sound velocity maxima and their depths of occurrence have been analysed (Fig. 4). Characteristics of the upper sound channel (axial velocity and axial depth) have also been analysed (Figs 5A and B). The depth contours in these charts are drawn at 40 m interval, isovels at 2 m interval and isohalines at 0.1‰ interval. The magnitudes of sound velocity perturbations have been analysed (Fig. 5C). To study the seasonal variations, especially in the upper layers, from spring to summer, 2 stations occupied in

the same region in February and April have been selected and vertical profiles of temperature, salinity and sound velocity presented (Fig. 6).

Results and Discussion

The following criteria have been followed for studying sound velocity structure. The upper sound channel is the ocean layer in which the sound velocity first decreases with increasing depth and after the minimum is crossed, it increases again, the layer thus acting as a wave guide, allowing the sound rays to propagate over long distances⁸. The depth below the channel axis at which the sound velocity is maximum is taken as the lower boundary of the upper sound channel. The depth above the channel axis at which the sound velocity is equal to the value at the lower boundary is taken as the upper boundary. Changes from a negative to a positive gradient in sound velocity or vice versa over small depth scales are termed as sound velocity perturbations³.

Vertical distribution of sound velocity along zonal sections—These sections were occupied in February when the influence of winter could still be seen as evident from a well formed mixed layer of relatively low temperature.

Sound velocity distribution along section I (Fig. 2A) is characterised by several high cells and a few low cells.

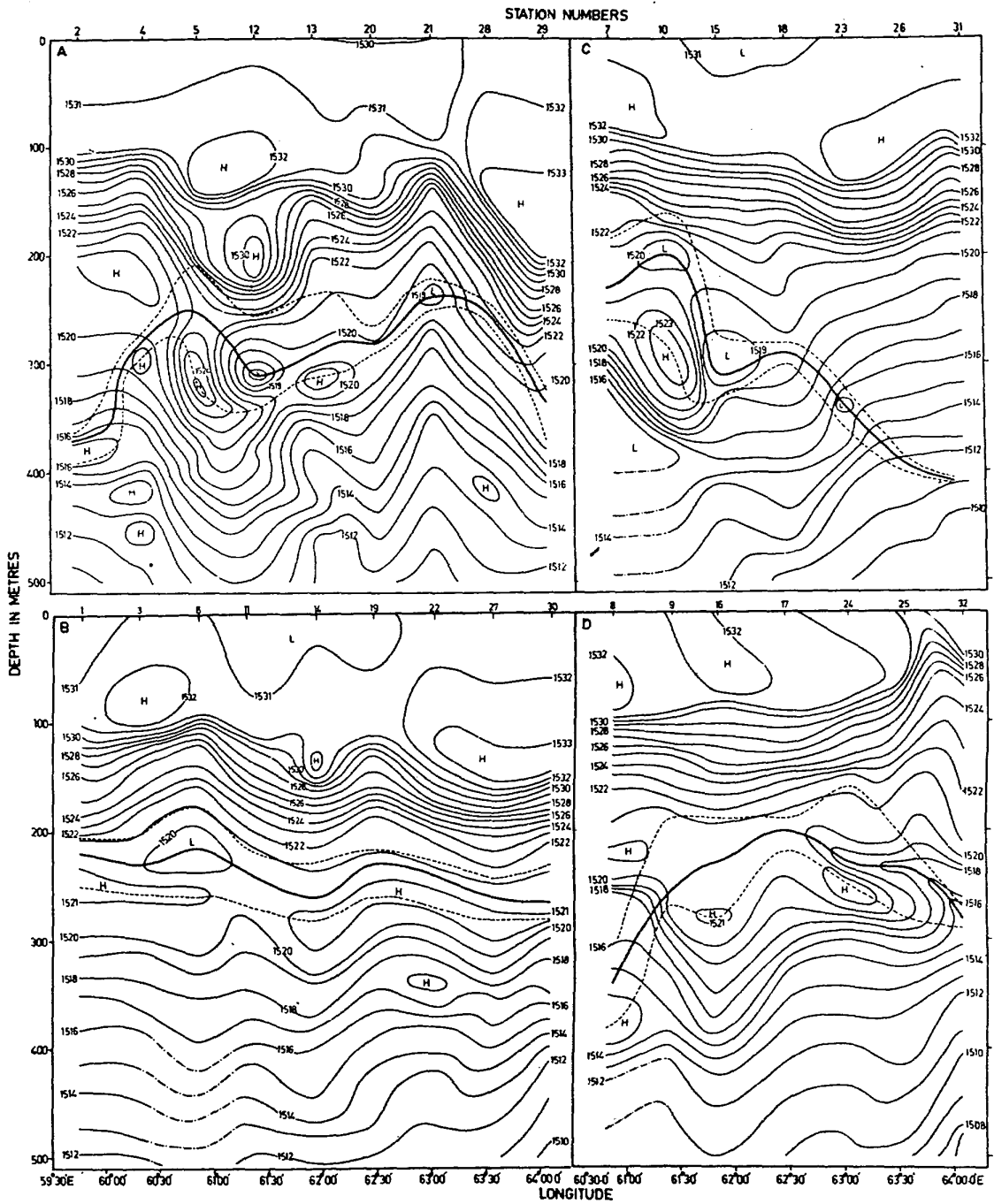


Fig. 2—Vertical distribution of sound velocity along latitude (A) 24°N (section I), (B) 23°30'N (section II), (C) 23°N (section III) and (D) 22°30'N (section IV)

There is a high velocity cell (> 1532 m/sec) around 120 m between sts 5 and 12 and a region of maximum sound velocity (> 1533 m/sec) on the eastern side between sts 28 and 29 around 150 m in association with a fairly thick mixed layer. The depth of velocline varies between 100 and 200 m. An interesting feature is the presence of cells of high sound velocity in association with salinity maxima at sts 4 and 12 around 210 m depth, which suggests that the Persian Gulf water spreads to a limited extent at shallower depths also. Sound channel is present throughout the section with its lower boundary coinciding with the salinity maximum of Persian Gulf water. The channel is wavy with the depth of its axis varying between 240 and 380 m. It is prominent with its thickness varying between 70 and 110 m at sts 5-13. The thick sound channel appears to be associated with the cells of sound velocity maxima resulting from the incursion of Persian Gulf water with its core located near the lower boundary of the channel.

At sts 1 and 11 - 19 (section II; Fig. 2B) the surface layer is characterised by low sound velocity (< 1531 m/sec). As in the case of the previous section, higher velocities (> 1533 m/sec) are found on the eastern side (between sts 22 and 30). In general, the isovels are parallel and wavy. The depth of velocline varies between 90 and 150 m while that of the axis of sound channel varies between 220 and 260 m. The sound channel is moderately thick (50 to 80 m) throughout the section with a distinct lower boundary associated with the Persian Gulf high salinity water spreading at these depths. Below 300 m, the sound velocity gradually decreases right up to 500 m where the values decrease from 1512 m/sec on the western side to 1510 m/sec on the eastern side (near st 30).

In section III (Fig. 2C) the surface layer at sts 15-18 is characterised by low sound velocity (< 1531 m/sec) with relatively higher values (> 1532 m/sec) on the eastern and western sides. The depth of the velocline varies between 80 and 130 m. In general, the depth of the sound channel increases and its thickness decreases towards the east. The axial depth of the channel varies significantly (between 200 and 400 m). The prominent sound channel (thickness of 70-130 m) on the western side (at sts 7-10) is associated with the cell of velocity maximum resulting from the incursion of Persian Gulf high salinity water. An interesting feature of this section is the significant tilting up of isovels below the velocline, in the eastern half of the section.

Section IV (Fig. 2D) is the southern-most zonal section. Regions of maximum sound velocity (> 1532 m/sec) are encountered in the surface layer with fairly uniform values in the top 100 m on the western side. On the eastern side the sound velocity of the surface layer dropped to < 1531 m/sec. The depth of velocline varies

from 90 m on the western side to 20 m on the east. The axis of the sound channel occurs at > 300 m on the western side (st 8), shallows up to 200 m in the central part (st 17) and again deepens to 280 m on the eastern side (st 32). The thickness of the channel varies significantly, with a maximum of 90 m at sts 16 and 24 in association with the high velocity cell resulting from high salinity. The velocity contours below 200 m show very large oscillations. The lowest velocity in this section (1507 m/sec) is found around 500 m depth on the eastern side (at st 32).

Vertical distribution of sound velocity along diagonal sections—These sections have been occupied in late March, during which the transition conditions between winter and summer prevail. One characteristic feature of this period is the formation of seasonal thermocline resulting from intense surface heating.

Maximum sound velocities (> 1538 m/sec) are encountered in the surface layer in all the sections (Fig. 3). In association with seasonal thermocline, a velocline with fairly sharp gradients is present just below the shallow surface layer. The prominent vertical oscillations exhibited by the isovels in the velocline may be associated with internal waves. In section V, a region of high sound velocity is found around 90 m (at sts 63-62) in association with a salinity maximum. At sts 60, 57 and 53, the sound channel could be traced around 250 m in association with the cells of high sound velocity resulting from the Persian Gulf high salinity water. This feature suggests the presence of a sound channel in the outer slope region, oriented parallel to the shelf edge. This is associated with the tongue of Persian Gulf high salinity water which moves southwards along these stations. In section VII, the contours tilt up shoreward prominently at depths > 300 m. The minimum values of sound velocity in the diagonal sections are between 1509 and 1511 m/sec at 500 m.

Sound velocity distribution in relation to salinity maxima/water mass structure—The Persian Gulf water enters the Gulf of Oman through the strait of Hormuz and spreads in the Arabian Sea as a salinity maximum between 200 and 400 m⁹. Thus, this high salinity water mass lies sufficiently deep in the Arabian Sea¹⁰ to affect the sound velocity profile considerably.

Fig. 4(A) depicts the core values of subsurface salinity maxima associated with the Persian Gulf waters. The Persian Gulf waters enter as tongues of high salinity in the northern Arabian Sea. Maximum core values have been recorded at sts 5, 13, 70, 10 and 57 (respectively 36.65, 36.57, 36.46, 36.64 and 36.45 ‰). Salinity maximum was encountered at 2 or 3 levels between 200 and 400 m depth, at a few stations (Fig. 4A). This feature indicates that the Persian Gulf waters spread as high salinity tongues at 1 or 2 more levels

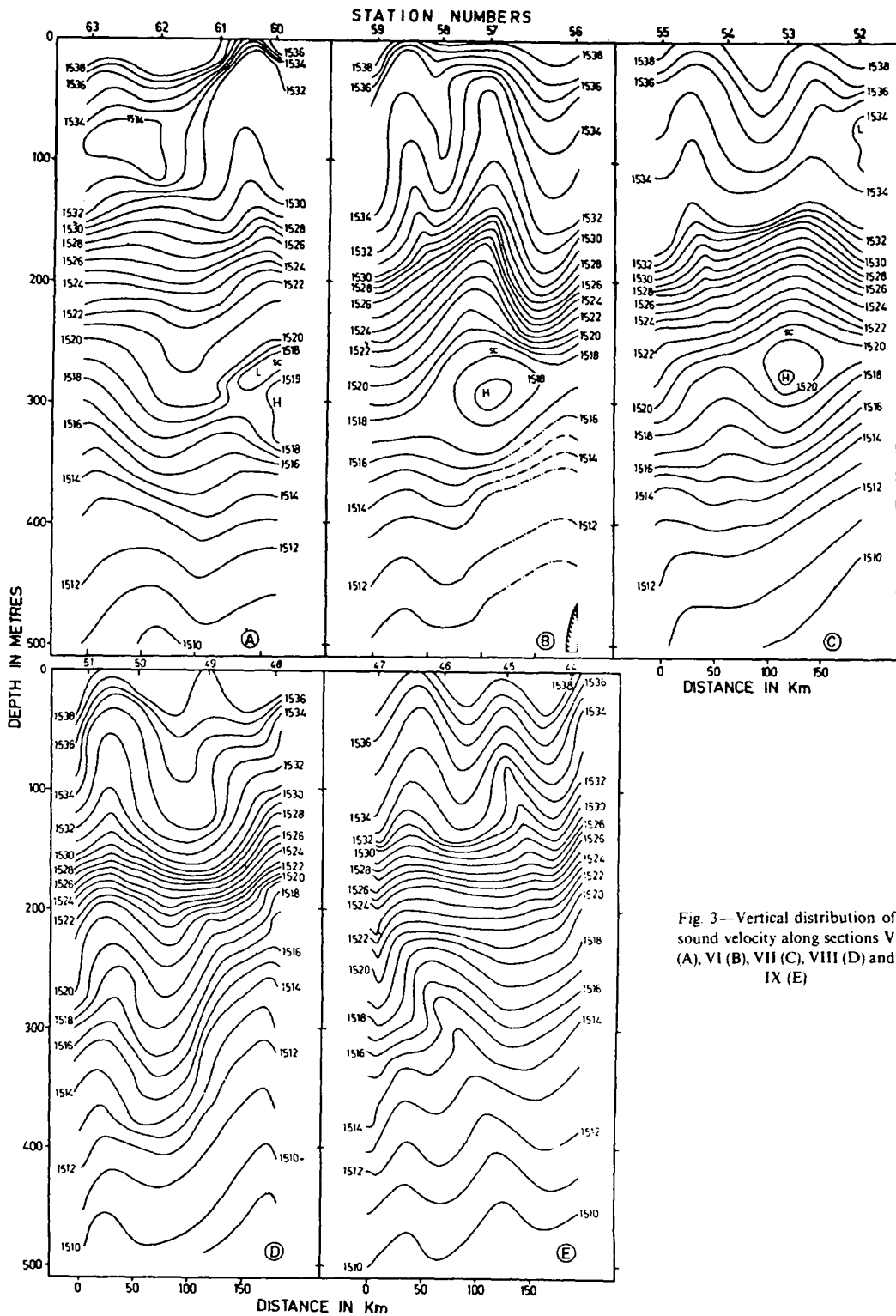


Fig 3—Vertical distribution of sound velocity along sections V (A), VI (B), VII (C), VIII (D) and IX (E)

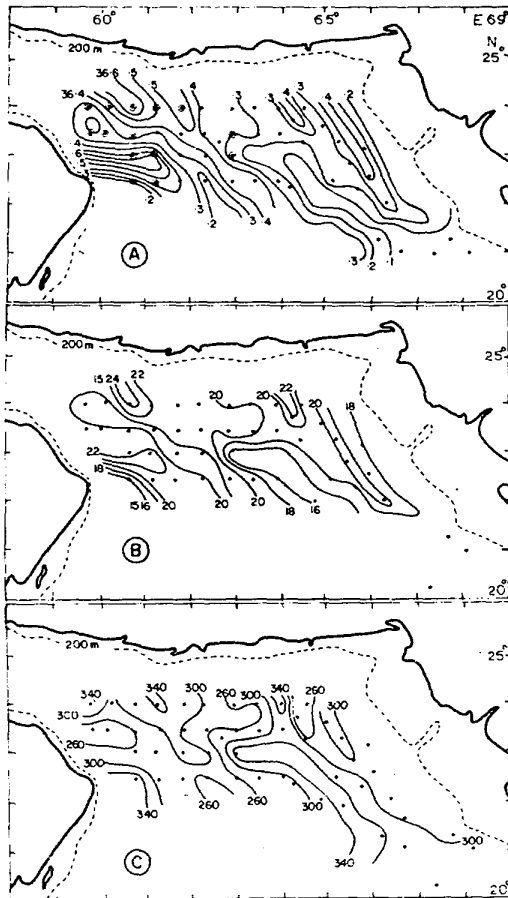


Fig. 4—(A) Core values of the subsurface salinity maximum associated with temperature inversion/constant temperature [Circles round the station dots indicate occurrence of salinity maximum at 2 or 3 levels] (B) Subsurface sound velocity maximum (C) depth of core values of the subsurface salinity maximum/sound velocity maximum

(up to limited extents) besides the prominent one characterised by temperature inversion and salinity maximum, causing significant sound velocity perturbations. Velocity maxima (> 1520 m/sec) have been observed in the regions where maximum core values of salinity are encountered (Fig. 4B). The depths of the core values of Persian Gulf water vary between 220 and 380 m, the most frequently encountered depth of the high salinity core being 300 m (Fig. 4C).

The axial velocity (Fig. 5A) varies between 1512 and 1522 m/sec and the axial depth (Fig. 5B) between 200 and 370 m. It is interesting to note that the sound channel is relatively shallow (200 - 290 m) with axial velocities of the order of 1519-1522 m/sec in the regions of high salinity cores.

Strong velocity perturbations (Fig. 5C) with magnitudes of the order of 3 - 5 m/sec are found near

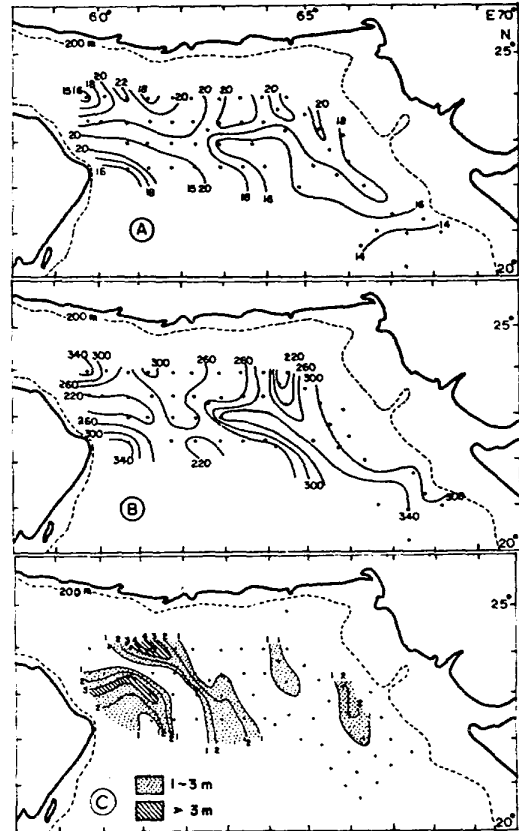


Fig. 5—Axial velocity (A) and depth (B) of upper sound channel and magnitude of sound velocity perturbations (C) [Perturbations < 1 m/sec shown by thick dots without shading or stippling at respective station locations]

the mouth of the Persian Gulf. It is seen that the upper sound channel is developed well (as indicated by the significant velocity perturbations) in the areas where the cores of Persian Gulf high salinity waters are present.

Vertical profiles of temperature, salinity and sound velocity—Vertical profiles of temperature, salinity and sound velocity in respect of stations occupied in February and April are given in Fig. 6. In general, the sound velocity profiles closely resemble the shape of temperature profiles emphasising the marked dependence of sound velocity on temperature rather than salinity. In February, the sea surface temperature is relatively low (around 23°C) and the mixed layer is developed well with thickness > 100 m. By April, a significant increase in sea surface temperature (by about 3.5°C) and the formation of seasonal thermocline due to intense surface heating are noticed. The corresponding increase in the surface sound velocity from February to April is 8-9 m/sec. Below

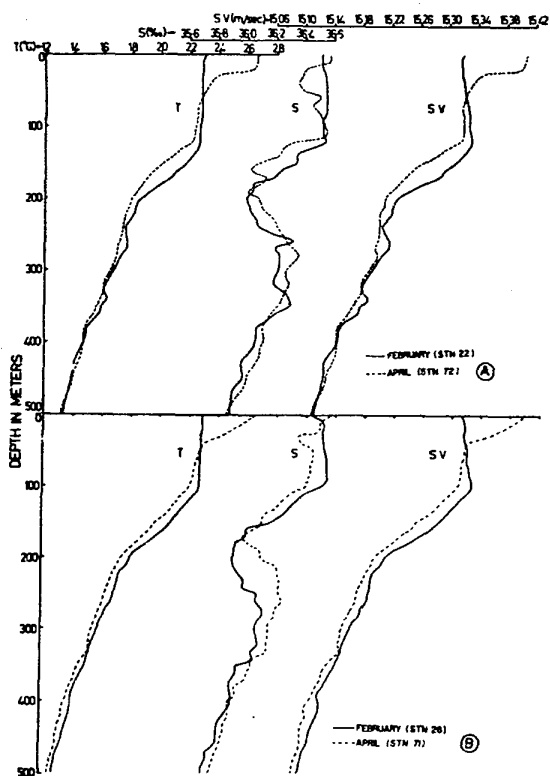


Fig. 6—Vertical profiles of temperature (T), salinity (S) and sound velocity (SV) in the central part of northern Arabian Sea depicting variations from February to April [(A) sts 22 and 72, (B) sts 26 and 71]

50 m, the temperature of the water is slightly less in April compared to that in February and the same

feature is seen in respect of sound velocity also. Unlike the temperature and sound velocity profiles, the salinity profiles are more complicated with alternate increase and decrease. At sts 22 and 72 (Fig. 6A), it is interesting to note the presence of upper sound channel in February, in association with the Persian Gulf high salinity water, at 260 and 340 m and a significant modification of this feature by April, suggesting seasonal variation in the flow paths of Persian Gulf high salinity water.

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