MIXING OF THREE WATER TYPES IN THE SOUTH ADRIATIC

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ABSTRACT

The mixing of three water types during six winter seasons in the south Adriatic was examined. The water types observed are the north and middle Adriatic water and the Mediterranean water. The distribution of determined proportions of their participation in the region observed for each water type has been obtained by means of T-S diagrams and a triangle of mixing specially applied. Considerable fluctuations in the occurrence of the Mediterranean water in the south Adriatic during the different winter seasons are most significant. The mixing between three water types observed in the south Adriatic form the south Adriatic water, which flows over the bottom layer of the Otranto strait in the Mediterranean.

INTRODUCTION

Four water types, occurring in the Adriatic, have recently been determined (ZORE-ARMANDA, in press). The material used is from the north, middle and south Adriatic (fig. 1) referring to the periods 1911-1914 and 1948-1958. The present paper deals with the occurrence of those water types in the south Adriatic deep, which is separated from the middle Adriatic by Palagruza sill, and from Mediterranean by the Otranto sill.

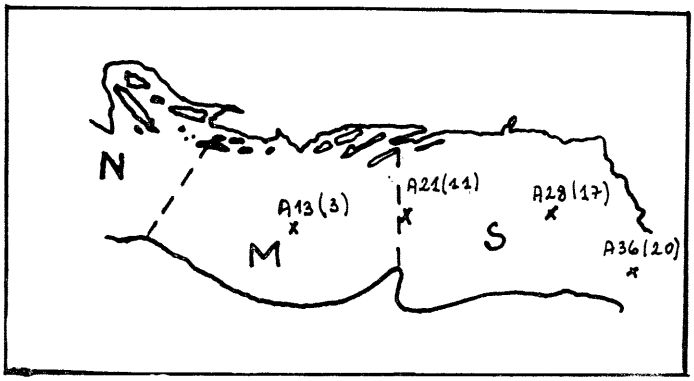

FIG. 1. — *Stations which refer to the* T-S *curves and the boundaries separating the north, middle and south Adriatic.*

The method used.

The water types found in the Adriatic are: the *S-water* having characteristics T = 11°C, S = 38,5 ‰, originally from the north Adriatic, the *M-water* having characteristics T = 12°C, S = 38,2 ‰, originally from the middle Adriatic, the *J-water* having characteristics T = 13°C, S = 38,6 ‰, originally from south Adriatic and the *A-water* having characteristics T = 14°C, S = 38,7 ‰, originally from the Mediterranean.

On the T-S diagram from the Middle Adriatic (fig. 2) three water types are present, i.e. the S, M and A-water. The M and S waters were present during one winter (1911) and the A and S water during the other (1914). It is assumed that the south Adriatic water represents the results of mixing of the above three waters. The present paper will therefore follow their proportional occurrence in the south Adriatic area in different winters.

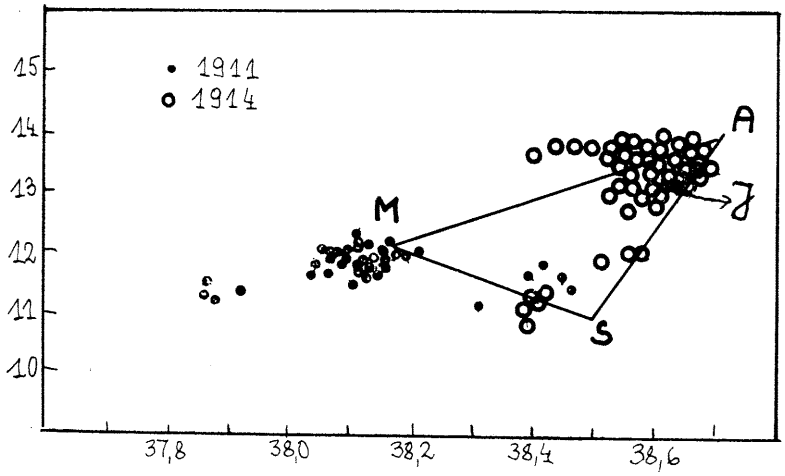

FIG. 2. — *T-S diagram for the middle Adriatic area for* 1911 *and* 1914 *winters. The triangle corners represent the* A, M *and* S *waters.*

To follow the changes in the proportional occurrence of the A, M and S waters, a triangle of mixing (fig. 3) has been constructed with segments showing the proportional occurrence of all the three water types, the rates being 25,50 or 75 p.c. A longitudinal profile through the south Adriatic area has been selected consisting of four stations lying between the middle

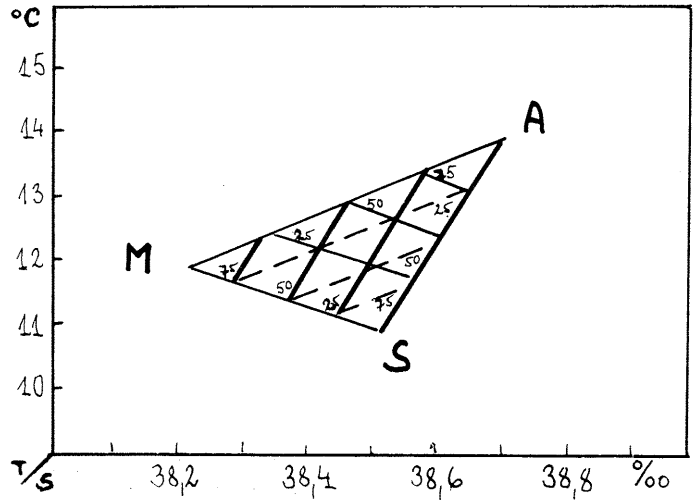

FIG. 3. — *Triangle of mixing by means of which the proportional occurrence in various depths of the* M, S *and* A *waters has been determined in the* T-S *curves.*

Adriatic and the Otranto strait. (Stations A13, A21, A28 and A36 of the "Najade" expedition correspond to the stations 3, 11, 17 and 20 of the "Igy" Yougoslav cruises 1957-58 and the 1962 cruise performed by the Institute of Oceanography and Fisheries, Split. For each station the T-S curve was made for each winter observed. The T-S curves were then drawn through

the triangle of mixing (fig. 3). This enables us to find the proportional occurrence of each type of water at any depth at any of the above mentioned stations (MILLER, 1950). The graphs (fig. 4 - 9) have thus been prepared to show, for each of the observed water type, the distribution

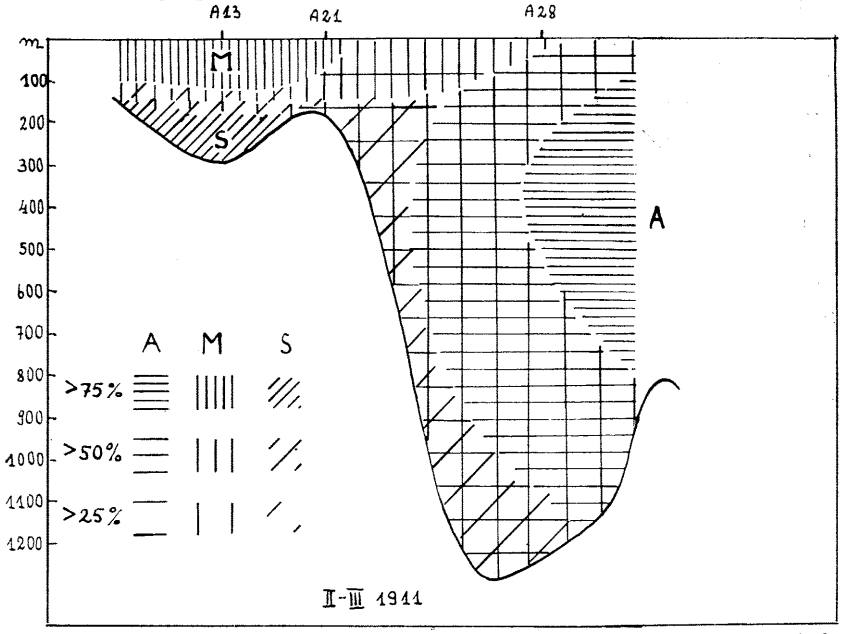

FIG. 4. — *Vertical section of the longitudinal profile through the south Adriatic with the proportional occurrence of the* A, M *and* S *waters in the profile during the* 1911 *winter season.*

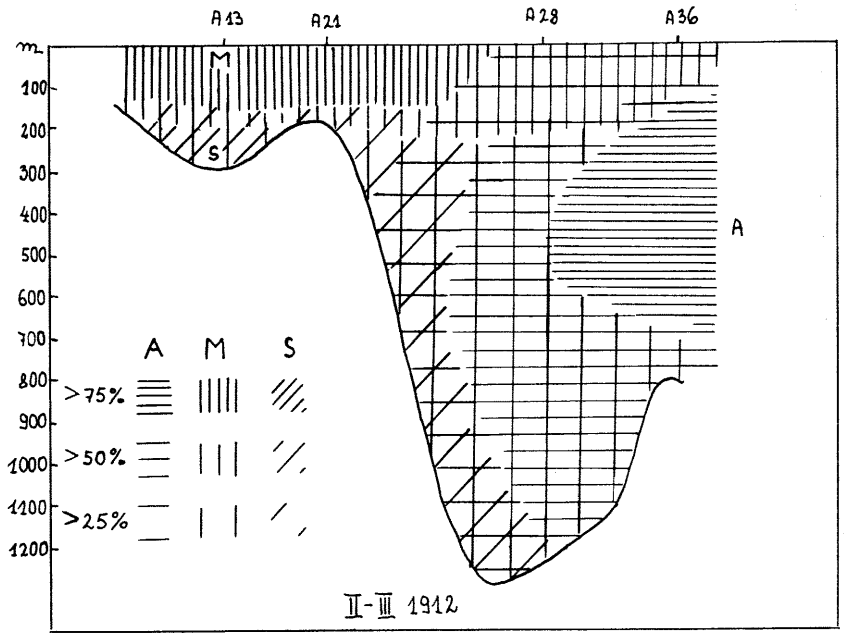

FIG. 5. — *Proportional occurrence of the three water types in the south Adriatic during the* 1912 *winter season.*

of the determined proportions along the profile. The higher proportions are shown by more thickly spaced lines. Six situations are shown in all covering the 1911, 1912, 1913, 1914, 1958 and 1962 winters.

Analysis.

Let us first examine the distribution of the A-water in the south Adriatic. This water is permanently present in the area, although its occurrence shows considerable fluctuations from

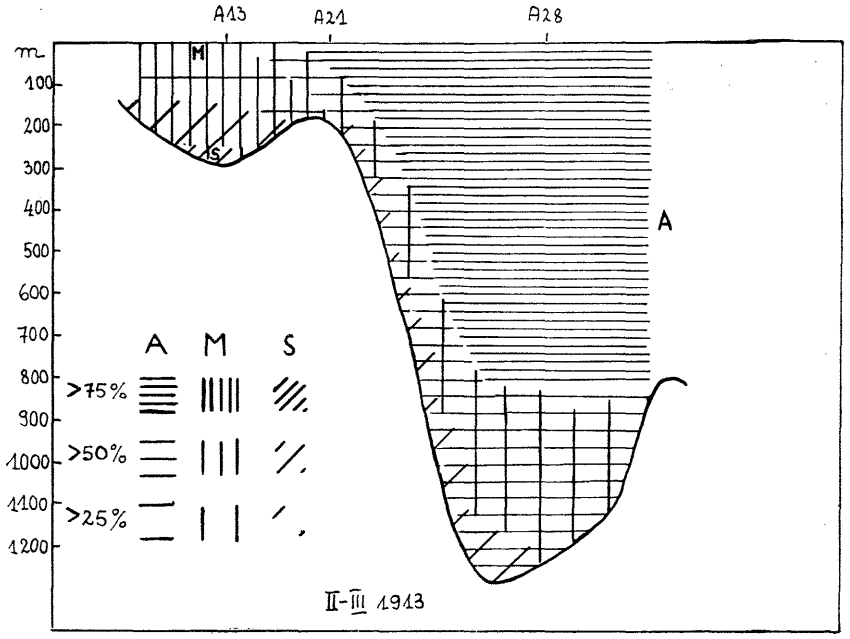

FIG. 6. — *Proportional occurrence of the three water types in the south Adriatic during the* 1913 *winter season.*

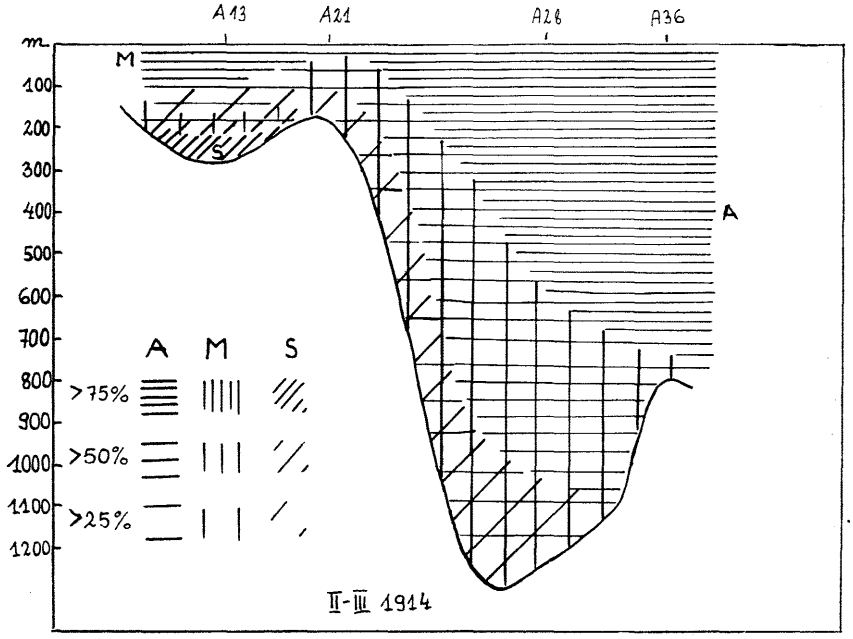

FIG. 7. — *Proportional occurrence of the three water types in the south Adriatic during the* 1914 *winter season.*

one winter to another. In the winters 1911 and 1912, for example, it appeared only in small quantities. In winters 1913, 1914 and 1962 the volume of A-water was considerable and in

winter 1958 it was average. During the winters of its low occurrence, A-water unmodified by mixing is found in the intermediary layer only, while it is present both in the intermediary and the surface layers during the winter of its higher occurrence.

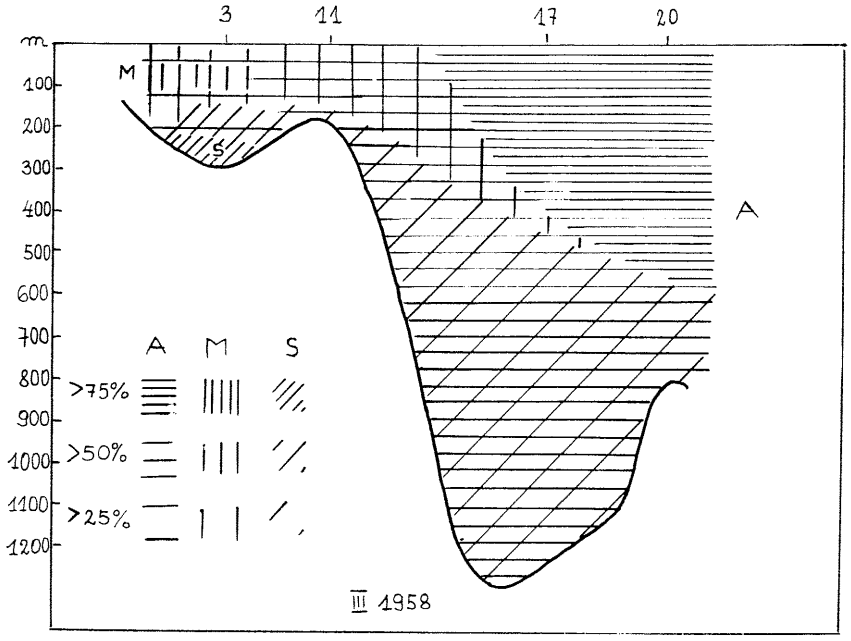

FIG. 8. — *Proportional occurrence of the three water types in the south Adriatic during the* 1958 *winter season.*

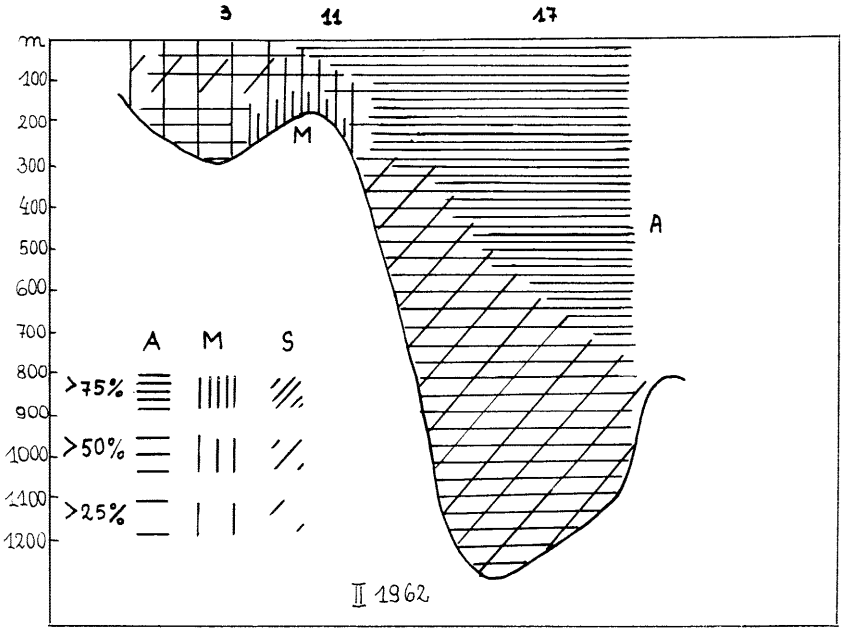

FIG. 9. — *Proportional occurrence of the three water types in the south Adriatic in winter* 1962.

A-water, mixing with the Adriatic water loses its characteristics quickly if the penetreting quantities are small. Winters, when small quantities of A-water penetrate into the Adriatic,

are favourable for the formation of the south Adriatic J-water. We can try to estimate the different quantities of the penetrated A-water by means of the diagrams, considering unmodified A-water only. By comparing a year of low occurrence of A-water (e.g. 1911) with a year of its high occurrence (e.g. 1914), we find that the quantitative ratio on the profile is about 1 : 5. This suggests that the quantities of Mediterranean water penetrating the Adriatic vary considerably from one winter to another. The fluctuating influence of the Mediterranean water on the Adriatic has been also found by BULJAN (1953).

The cause of this phenomenon has not yet been discovered. There is a suggestion that the higher A-water inflow into the Adriatic may be a consequence of the rising of the intermediary layer in the Ionian Sea. This seems to be in greement with the graphs. Unmodified A-water is present only in the intermediary layer in the Otranto strait during the winters of its lower occurrence, while it is found in both the intermediary and surface layers in the winters of its higher occurrence.

M-water not modified by mixing appears only occasionally in the south Adriatic, and then merely in the surface layer, during the winters with a lower occurrence of A-water. Only A and M waters unmodified appear in the surface layers due to their lower density compared to the S water (σ_t = 29,09 for M-water, σ_t = 29,06 for A water and σ_t = 29,52 for S water). Otherwise, M-water is generally present in the south Adriatic in a proportion between 25 to 50 %, but in 1962 winter it did not appear at all. For this season the water of the area showed slightly different characteristics in 1962. M-water is found in higher proportions in the surface layer during winter seasons with a low occurrence of A-water. In other winters it is predominantly below the surface layer between the A-water at the surface and partial S water near the bottom. The three water types are stratified due to their density, A-water being the lighest, M-water somewhat heavier, and S-water the heaviest (σ_t = 29,52). S-water is permanently present in the South Adriatic deep, but only found as mixtures with other waters. Because of his high degree of density it is never found near the surface. The observations have never disclosed S water in percentage greater than 75 %.

In the formation of J-water within the triangle of mixing, the three water types participate in the following proportions: A-water 63 %, M-water 11 %, and S-water 20 %. The enclosed diagrams show that the ratio of occurrence of M and S waters varies from one winter to another. It seems that the M-water is predominant in the M-S ratio during the years with low A-water participation, while the S-water influence increases when the A-water participation is high. This is in connexion with the origin of M and S waters. The M-water is formed by convection in the middle Adriatic in the periods when A-water is absent in the area, i.e. when the advection of water is generally low. The S-water, being of the north Adriatic origin, is in condition to penetrate to the south Adriatic only in the years of the stronger surface water advection, influencing the bottom advection as well, i.e. when the A-water influence increases.

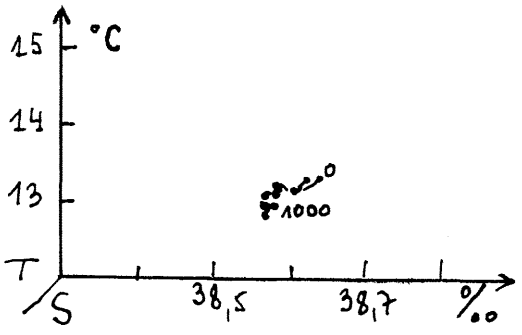

FIG. 10. — T-S *curve for the station A* 28 (south Adriatic) *for the winter* 1911.

The fact that M, S and A water types are permanently found in the south Adriatic obviously demonstrate that the water in the area is a result of mixing of the three water types. This is also confirmed by the circumstance that all the three water types most often occur, mixed together, in the bottom layer of the south Adriatic deep. The J-water formation is favoured by considerable convective mixing of water taking place when the surface water happens to be heavier. This occurs in the winters when the influence of A-water is small, since this water, as has already been said, has the least density (σ_t = 29,06). A more intensive convective mixing

of water occurs then in the years when the A-water influence in the south Adriatic is less significant. The 1911 T-S diagram is an example of this intensive mixing as almost all the data practically converge towards a single point (fig. 10).

There is also the question of overflowing of the south Adriatic water into the Mediterranean over the Otrante sill. According to an earlier opinion of the author, the occurrence of the south Adriatic water in the bottom layer in the Otranto Strait is limited to winters with a pronounced inflow of A-water into Adriatic. As evident from fig. 5, however, the bottom layer in the Otranto Strait contained AM water (which is at least in part south Adriatic water) in the year 1912 too, i.e. in a period when the influence of A-water in the Adriatic was not significant. Still the influence of south Adriatic water in the Otranto strait is much more stronger during the years showing a considerable advection of A water into the Adriatic (e.g. in 1958).

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