DEEP WATER MOVEMENTS IN THE ADRIATIC
(A Preliminary Report)

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SUMMARY

On the basis of T - S diagram analasis, the conclusions are drawn for movements of water in the intermediate and bottom layer in the Adriatic for different seasons. The differences in current system in periods of high and low salinity of Adriatic water are discussed. The results are prooved by water transport calculation done by the help od dynamic depths data.

The general conclusion is that in summer there is a tendency of water inflow in intermediate layer, and in winter in surface layer. This tendency is much more pronounced in the period of high salinity of Adriatic water. The outflowing tendency of Adriatic water in the bottom layer is indicated in summers caracterised by low salinity of Adriatic water, and in winters caracterised by high salinity of Adriatic water.

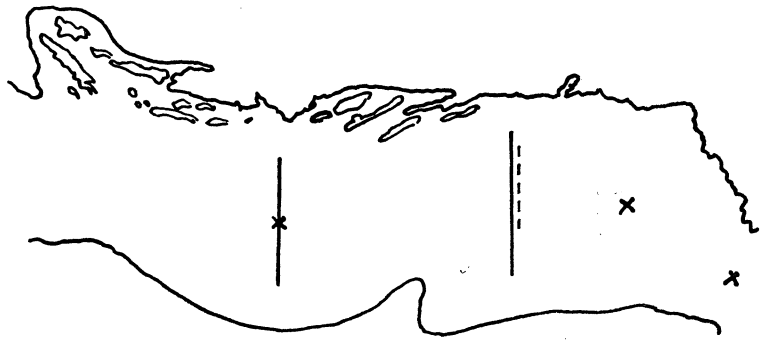

FIG. 1. — *The mid-Adriatic and south Adriatic profiles referred to in the computation of water transport. Profile which for is calculated, the water transport in the surface layer of the south Adriatic is shown by a full line, and in the intermediary layer by a dashed line. The stations situated in the mid-Adriatic, south Adriatic, and the strait of Otranto, involved in the T-S diagrams, are marked with little crosses.*

In the course of attempts to determine the water types in the Adriatic sea, their distribution during the various seasons has been studied too. From this study the conclusions has been drawn about the water movements occuring in the intermediary and bottom layers. We have to distinguish, however, the period when the inflow of Mediterranean water into Adriatic is generally an intense one from the period when it dwindles. These alternating periods extend over series of years and differ from each other, in the first place, in salinity and temperature values of the Adriatic water (BULJAN, 1953, 1957). The periods of abundant inflow of Mediterranean water are characterized by the higher salinity of the Adriatic water.

There is a change in the system of surface currents during the above mentioned periods too (ZORÉ, 1956). In a similar way, the system of surface currents undergoes seasonal changes in the course of year owing to significant fluctuations of the hydrographic factors. The most characteristic seasons (winter, summer) in the periods of higher and lower salinity of Adriatic water will be considered in this paper.

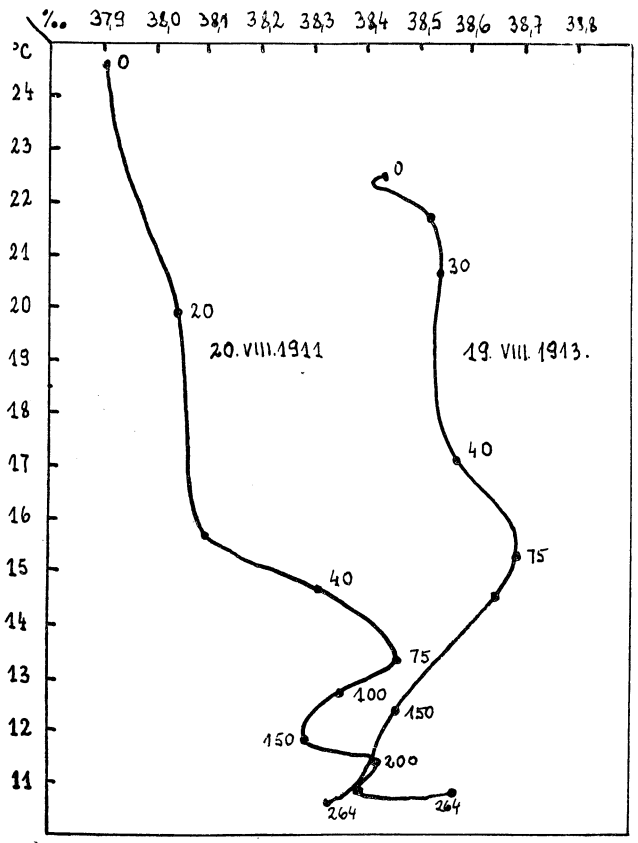

FIG. 2. — *T-S diagrams for the mid-Adriatic. The depths are given in metres. In* 1911 *the salinity values were generally lower and the intermediary layer of high salinity water was less marked. Three water layers are distinct in* 1913, *the surface layer with a higher temperature value and a low salinity one, the intermediary layer with a higher salinity value and a medium temperature one, and the bottom layer with the lowest values of both salinity and temperature.*

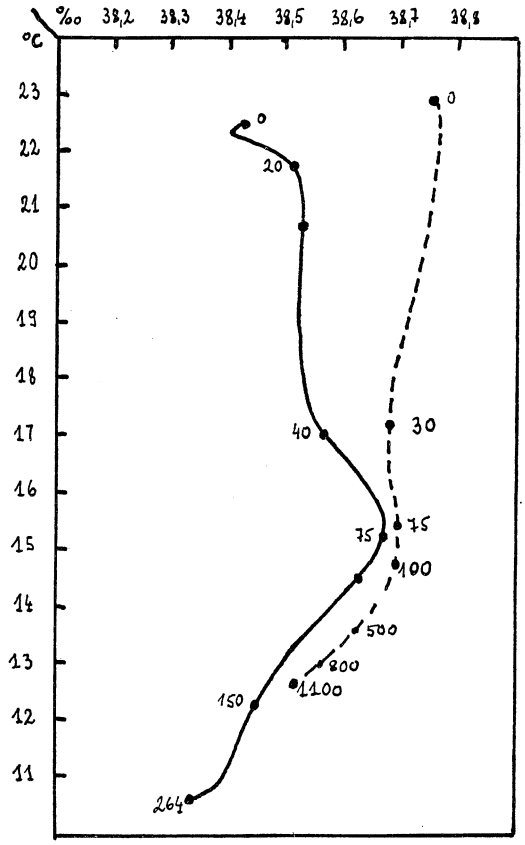

FIG. 3. — *T-S diagrams referring to the mid-Adriatic* (full line), *and south Adriatic* (dashed lined) *in august* 1913. *The water of the intermediary layer in the south Adriatic displays a higher salinity value which decreases as the water proceeds towards the mid-Adriatic. Three water layers are markedly evident in the mid-Adriatic. The depths are given in metres.*

Summer. A vertical stratification of the sea water into three layers takes place in this season (fig. 2 and 3). There is a general trend of the water in the surface layer (0-50 m) to flow out from the Adriatic, mainly along the west coast. The water of this layer is characterized by a relatively high temperature and a low salinity. The intermediary layer extends from 50-150 m in the middle Adriatic, and from 50 to about 500 m in the south Adriatic, but the boundary depth changes from year to year. In this layer the Mediterranean water of higher salinity is found, what indicates a water movement in the opposite direction than in the surface layer.

By vertical mixing with the less saline Adriatic water, the incoming Mediterranean water gradually loses its characteristics on its way from the strait of Otranto to the mid-Adriatic where it is still distinct (fig. 3). The intermediary layer, like the surface one, displays changes in the transport of water in a different years. During the lower salinity period of the Adriatic water a more intensive water transport from the Adriatic to Mediterranean is find in the surface layer, and a less intensive one in the intermediary layer.

To get an idea of the quantitative difference of water transport in the different years, the water transport has been calculated for one middle Adriatic profile (across Jabuka Pit) and for one south Adriatic profile (fig. 1). The calculation has been done from dynamic depths data (ZORÉ, 1956), based on the material of the « Najade » and « Ciclope » expeditions. The years 1911 and 1913 have been picked out, the former belonging to the characteristic period of lower and the later to the higher salinity period of Adriatic water.

Period	Depth (m)	Volume transport 10^{-4} km³/sec	Average salinity for 0 — 200 m ‰
	Middle Adriatic		
VIII/1911	0 — 100	— 0,47	38,2
VIII/1913	0 — 100	— 0,27	38,5
	South Adriatic		
VIII/1911	0 — 100	— 1,40	38,4
VIII/1913	0 — 100	— 0,11	38,6

TABLE I.

The water transport of the outflowing current (marked —) in the surface layer was in 1911 almost two times bigger than in 1913 in the middle Adriatic, and even 14 times bigger in the south Adriatic.

Period	Depth (m)	Volume transport 10^{-1} km³/sec	Average salinity (0-200 m) ‰
VIII/1911	0 — 100	— 0,47	38,2
VIII/1911	100 — 200	— 0,53	
VIII/1913	0 — 100	— 0,27	38,5
VIII/1913	100 — 200	+ 1,07	

TABLE II. — Middle Adriatic.

The direction of the water movement in the intermediary layer of the middle Adriatic in 1911 was the same as observed in the surface layer, i.e. the characteristic summer water movement in this layer did not take place at all. It is seen on the T-S diagram referring to the middle Adriatic area in the summer 1911 (fig. 2) that the intermediary layer, characterized by

more saline water appeared at the 75 m depth, which is not comprised in the above computation for the intermediary layer. In 1913, however, a pronounced transport of the inflowing water movement (marked +) took place in the intermediary layer, and it was even five times as great as the transport of the outflowing surface current in the same year.

Period	Depth (m)	Volume transport 10^{-4} km³/sec	Average salinity (0-200 m) ‰
VIII/1911	0 — 100	— 1,40	38,4
VIII/1911	100 — 200	+ 1,00	
VIII/1913	0 — 100	— 0,11	38,6
VIII/1913	100 — 200	+ 2,10	

TABLE III. — South Adriatic.

There is a transport of the inflowing current in the intermediary layer in the south Adriatic in both 1911 and 1913, but it is twice as great in the latter year as in the former. Also

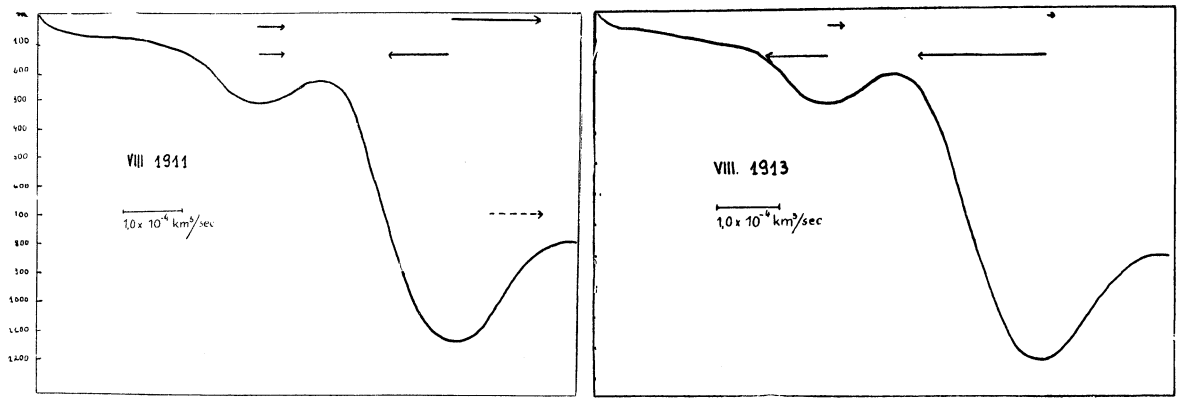

FIG. 4 and 5. — *A schematic survey of the vertical cross-section of summer water movements in the Adriatic (0-1200 m).* Left: *during a low salinity period; the trend of water outflow is predominant, and there is advection of the Adriatic bottom water to the Mediterranean.* Right: *during a high salinity period; the trend of water inflow, occuring in the intermediary layer, is predominant; advection of the Adriatic water to the Mediterranean does not take place in the bottom layer.*

it is in 1913 almost 20 times bigger than the transport of the outflowing surface current. In 1911, on the contrary, the transport of the outflowing current in the surface layer was even bigger than the transport of the inflowing current in the intermediary layer. It is necessary to point out, however, that the water transport data for the surface and intermediary layer in the south Adriatic have been obtained from different profiles, which gives to the comparison an informative value only.

Tables I, II and III prove anyhow, that in summer there is an outflowing trend in the surface layer, and the inflowing one in the intermediary layer. During the years of hifher salinity values, however, the outflowing trend in the surface layer is less pronounced, and the inflowing one in the intermediary layer is more pronounced. On the contrary, during the years of lower salinity values, the outflowing trend of water in the surface layer is more pronounced, and the inflowing one in the intermediary layer is less pronounced.

During the low salinity summers the bottom layer in the Otranto Strait contains water found to be of south Adriatic origin as it is less saline than the Mediterranean water usually occuring in the bottom layer of the above-mentioned strait (fig. 6). The conclusion has been drawn therefrom that an adversion of the Adriatic water to the Mediterranean in the bottom layer too takes place during the low salinity summers. The situation is then the following : during the low salinity summers there is an pronounced advection of water from the Adriatic to the Mediterranean in the surface and bottom layer, while there is an pronounced advection of Mediterranean water to the Adriatic during the high salinity summers in the intermediary layer.

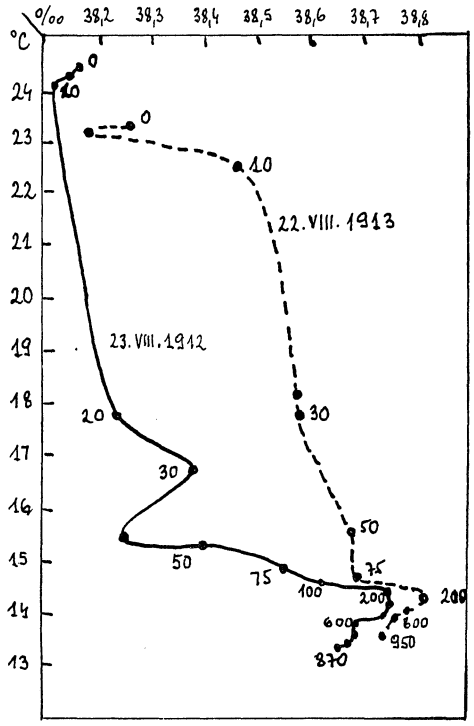

FIG. 6. — *T-S diagrams referring to the strait of Otranto during the periods of low salinity (*1912*) and high salinity (*1913*). The water found in the bottom layer during the low salinity period displays low temperature and salinity values and its characteristics agree with those of the south Adriatic water. The depths in the diagrams are given in metres.*

Winter. A vertical stratification of water into two layers occurs in winter (fig. 7). The surface layer is characterized by the inflow of water in the Adriatic. This water inflow takes place mainly along the eastern coast in the about 100 m deep layer. The surface current is very pronounced during the years of more saline water while is almost none during the years of less saline water (fig. 8). Direct current measurements proved such changes in the current system (ZORÉ, 1960). A water movement in the opposite direction takes place in the bottom layer during the years of high salinity values when a considerably cooled water, coming from the north Adriatic, descends to the bottom layer of the middle Adriatic and, to some extent, to the bottom layer of the south Adriatic as well. From the south Adriatic there is an outflow of water in the bottom layer to the Mediterranean in the same winters. During the high salinity winters, then, a considerable water inflow in the Adriatic occurs in the surface layer, but there is also a water movement in the opposite direction in the bottom layer, so in such winters the south Adriatic water flows into the Mediterranean. During the years of low salinity values the water inflow in the surface layer dwindled, and it was not possible to find out whether an outflow took place in the bottom layer. Low salinity winters, therefore, can be considered as winters with a highly diminished water advection. Such winters are therefore suitable for the formation of the genuine Adriatic water type.

To get an idea of quantitative differences in water transport during the periods of higher and lower salinity of water, on table IV is given the water transport in the middle Adriatic in a winter with a markendly low salinity of water (1912) and a winter with a markendly high salinity of water (1914).

The water transport value obtained by computation is as much as thirty times smaller during a winter in the low salinity period than during a winter in the high salinity period. It is difficult to say, however, how far the above ratio is a real one, but analyses of some other kind

have shown that the advection is considerably smaller during the winters of lower salinity values, particularly in the middle Adriatic area.

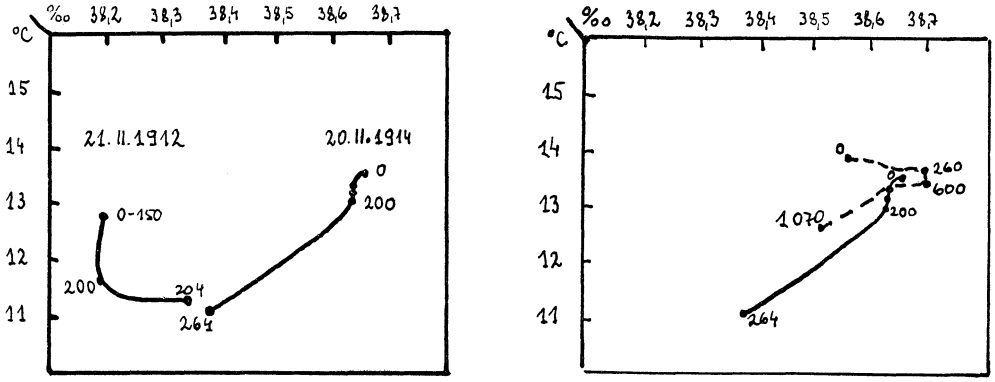

FIG. 7 and 8. — Left : *T-S diagrams referring to the mid-Adriatic in the winter season; two water layers are markedly evident; the water found in the bottom layer shows identical characteristics during the periods of both high and low salinity; the water found in the surface layer during a low salinity period* (1912) *was less saline than during a high salinity period* (1914).

Right : *T-S diagrams referring to the mid-Adriatic* (full-line) *and south Adriatic* (dashed line) *in february and march* 1914 *respectively; the water of the surface layers of both areas shows identical characteristics during the high salinity period.*

Period	Depth (m)	Volume transport 10^{-4} km³/sec	Average Salinity (0-200 m) ‰
II/1912	0 — 200	— 0,06	38,3
II/1914	0 — 200	+ 1,86	38,6

TABLE IV. — Middle Adriatic.

Differences in the water transport in the intermediary and bottom layer during different years are discused and proved by dynamic calculations. They are conuected to the differences in sea water characteristics in different years.

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BIBLIOGRAPHY

BULJAN (M), 1953. — Fluctuation of salinity in the Adriatic. — *Rib. Biol. eksp.* « *Hvar* », *Izvjesca, Reports, Split,* **2** (3).

— 1957. — Fluctuation of temperature in the waters of the open Adriatic. — *Acta Adriatica*, Split, **6** (7).

ZORÉ (M.), 1956. — On gradient currents in the Adriatic sea. — *Acta Adriatica*, Split, **6** (7).

— 1960. — Preliminary results of direct current measurements in the Adriatic. — *Rapp. et P.V. Comm. int. Explor. Sci. Mer Médit.*, **15** (3).