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CHARACTERISTICS, SPREADING AND MIXING OF THE INTERMEDIATE WATER MASS AND THEIR SEASONAL VARIATIONS IN THE EASTERN MEDITERRANEAN

KARAKTERISTIKE, ŠIRENJE I MIJEŠANJE INTERMEDIJARNE VODENE MASE I NJENE SEZONSKE VARIJACIJE U ISTOČNOM MEDITERANU

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About 2009 hydrographic stations were taken in the Eastern Mediterranean (1948—1972) and used to study the characteristics and the spreading of the Intermediate water mass which is identified by subsurface salinity maximum. In this analysis the core method was used. The mixing rations of the main components forming the Intermediate water mass, which are the Levantine and Adriatic water types in addition to the Atlantic one are determined using the triangle of mixing as a nomogram.

The distributions of the salinity in the core of the Intermediate water mass as well as of the mixing rations of the Levantine water type indicated the westward flow from Levantine to Ionian Sea. In the Ionian Sea both the northward flow (towards the Adriatic different seasons. The asymmetry between the NE and the NW of the Ionian Sea as well presented by salinity and mixing ratios distributions, with dominance of ADWT in the NW and the dominance of the LWT in the NE. This asymmetry indicates the influence of the Coriolis force on the water mass movements.

INTRODUCTION

The vertical structure of the water masses in the Eastern Mediterranean has mainly four layers; the surface, the Atlantic, the intermediate and the deep waters. The Atlantie water mass is detected by a subsurface salinity minimum, while the Intermediate one (IWM) has a maximum salinity between 150 and 500 meters. This stratification is well presented in late spring and summer, while in the late autumn and winter the strong vertical convection makes the surface and Atlantic waters well mixed with the IWM below them.

The salinity distribution in the core of the IWM in the Eastern Mediterranean has been studied by Lacombe and Tchernia (1960), Wüst (1961) and Lacombe and Tchernia (1972), and others.

In spite of these studies the characteristics of the IWM still needs more detailed investigation. This paper will throw more light on the main two questions.

a) Which are the main water types (or components) contributing to the formation of the IWM of the Eastern Mediterranean?

b) Which are the percentages of each of these components and their prefered paths in the Eastern Mediterranean in different seasons?

MATERIALS AND METHODS

The hydrographic data, published by the International Oceanographic data center, for the period 1948—1972, including about 5000 stations, were used in this analysis. After the examination of the vertical stability of these data (Brest Computer Center, at Laboratoire d'Océanographie Physique au Muséum d'Histoire Naturale, Paris), only 2000 stations were found to be adequate to be used in this study.

Our study of the characteristics and spreading of the IWM in the Eastern Mediterranean, is based on three methods:

1 — The conventional T — S analysis.

2 — The distribution of the maximum salinity i.e the core method.

3 — The determination of the rations of the components of the IWM using a triangle delineated by

a — Levantine waters type (LWT) (16.2°C, 39.12) (El-Gindy, 1983)

b — Adriatic water type (ADWT) (13.0°C, 38.60) (Lacombe and Tchernia, 1958)

c — Atlantic water mass at Sicily straits (16.0° C, 37.5) (El-Gindy, 1983)

RESULTS

A — *Seasonal variations of the Θ — S diagram of the IWM.*

The Θ — S diagram of the core layer of the IWM in the Eastern Mediterranean is shown in Fig. 1. This figure shows that Θ — S points of the Ionian Sea are less scattered than in the Levantine Sea. The envelope of the data points shows that the characteristics of the Levantine water type are as follows:

	Winter	*Spring*	*Summer*	*Autumn*
T	15.2°C	16.2°C	15.5°C	15.80°C
S	39.03‰	39.12‰	39.05‰	39.10‰
σ∅	29.0	28.88	29.0	28.98

Since, the spreading of the IWM begins in spring, after the winter formation, the spring point was taken as an index for the LWT.

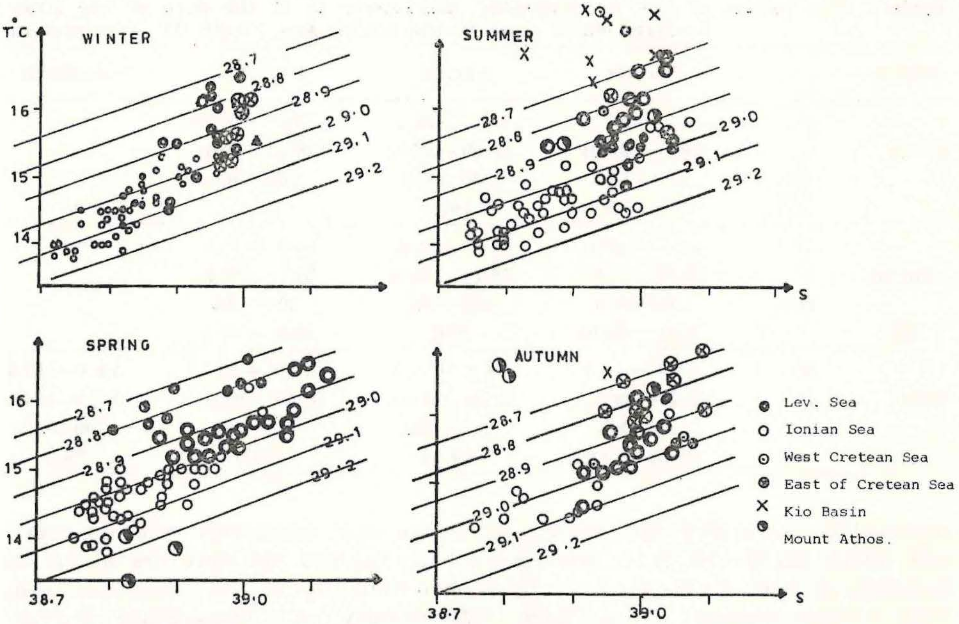

Fig. 1. (Θ — S) diagrams of the core of the intermediate water mass in the different seasons in the Eastern Mediterranean.

Other detailed characteristics of the core layer are shown in Tables 1. and 2. The core layer exists at depths 100—350 m and 150—500 m in the Levantine and Ionian Seas respectively. In the Levantine Sea the density in the core is

Table 1. The ranges of the hydrographic characteristics of the core of Intermediate water mass in the Levantine Sea (depth 'D' is in meters).

Season Region		Winter	Spring	Summer	Autumn
North and Central	T	15.4 —16.5	15 —15.5	15.6 —16.7	15.3 —16.1
	S	38.95—39.08	38.8 —39.1	38.96—39.04	38.96—39.04
	D	100—300	100—300	100—400	150—250
	σ ∅	28.9 —29.05	28.9 —29.0	28.75—28.8	28.9 —28.95
South	T	15 —16.2	15.4 —16.4	15.4 —15.9	15.2 —15.8
	S	38.88—39.02	38.81—38.95	38.29—39.05	38.92—39.01
	D	200—300	150—300	150—400	200—250
	σ∅	28.8 —28.9	28.75—28.95	28.85	28.85
West	T	14.5 —15.7	15.2 —15.7	15.2 —15.9	14.7 —16.20
	S	38.89—38.95	38.90—39.04	38.87—39.05	38.92—39.05
	D	200—350	200—300	100—300	180—270
	σ∅	29.0	28.90	28.85	28.90
East	T	15.50—16.60	15 —16	15.3 —16.5	15.8 —16.5
	S	38.99—39.10	38.9 —39.1	38.97—39.03	38.98—39.04
	D	—	105—300	150—200	150—300
	σ∅	28.9	28.9	28.80	28.90

Table 2. The ranges of the hydrographic characteristics of the core of the Intermediate water mass in the Ionian Sea (depth 'D' is in meters).

Region		Winter	Spring	Summer	Autumn
	T	14.7 —15.15	13.7 —14.5	13.9 —14.70	—
North	S	38.72—38.91	38.69—38.92	38.76—39.0	—
	Dm	150—500	250—500	200—500	
	σ∅	29.0 —29.1	19.10	29.1	
	T	14.0 —15.8	14.3 —15.2	14.0 —15.2	
Central	S	38.72—38.95	38.78—38.93	28.72—39.0	
	Dm	200—500	200—500	200—500	
∅ρ		28.9 —29.05	29.0	29.0 —29.1	
	T	14.3 —14.5	14.4 —15.0	14.0 —14.8	14.3 —14.9
West	S	38.70—38.82	38.78—38.90	38.75—38.90	38.76—38.83
	Dm	150—400	200—400	250—400	200—300
	σ∅	29.00—29.05	29.10	29.05	29.0

confined between 28.9 and 29.0 except in summer when this value is relatively lower (29.75—28.85). In the Ionian Sea, Table 2, the core lies along the isopycals of 29.0—29.10, with density higher than that in the Levantine basin. This density increase is associated with salinity and temperature decrease (Fig. 1) indicating more mixing with deeper waters with highest content of ADWT in the Ionian Sea.

It is reasonable to consider t hesurface with σ∅ = 29.0 as a common isopycnal surface for the IWM in the Eastern Mediterranean. The IWM in the North of the Aegean Sea is quite variable indicating significant seasonal changes. The points of the Θ — S diagrams in the Levantine and Ionian Seas seperately could be fitted to straight lines expressed by ($\Theta = b + mS$), where Θ is the potential temperature, S is the salinity, b and m are constants to be determined by the least square method.

Table 3 A show significant correlation coefficients between Θ and S in all seasons in the Eastern Mediterranean except in the Levantine Sea in winter when turbulence and vertical convection are more pronounced. On the

Table 3 A. Linear regression analysis of T — S diagrams of the core of the Intermediate water ($\Theta = b + mS$) in the Ionian and Levantine Seas (r = correlation coefficient)

Region		Winter	Spring	Summer	Autumn
	b	—249.86	—165.55	—136.42	—123.11
Ionian Sea	m	6.81	4.64	3.88	3.55
	r	0.96	0.80	0.75	0.70
	b	—189.51	— 96.92	—160.75	—248.26
Levantine Sea	m	5.26	2.89	4.53	6.77
	r	0.46*	0.48	0.41	0.59

* non-significant at 95% level.

other hand the correlation coefficients in the Ionian Sea are higher than in the Levantine Sea since the T-S variations in the first basin are mainly controlled by mixing. For the comparison of the different models, the potential temperature has been estimated from the equations of the different seasons at fixed salinities: 38.75 and 38.0 in the Ionian Sea, and 38.95 and 39.0 in the Leventine Sea (Table 3 B). The different models gave nearly the same result with small differences; hence the IWM has stable characteristics except in the period of formation in the Levantine basin.

Table 3 B. Estimated potential temperature from linear equations in the Eastern Mediterranean in different seasons at fixed salinities.

Season Region		Winter	Spring	Summer	Winter	mean	Stand. dev.
Ionian	38.75	14.09	14.17	14.14	14.33	14.18	± 0.09
	38.9	15.11	14.87	14.73	14.86	14.89	± 0.14
	38.95	15.45	15.64	15.61	15.39	15.52	± 0.10
Levantine	39.0	15.71	15.79	15.83	15.73	15.76	± 0.05

B — *Salinity distribution in the IWM core layer:*

The seasonal fluctions of the salinity maximum in the core layer of the IWM in the Eastern Mediterranean can be shown by Figs. 2, 3, 4 and 5. These charts have certain common features which are worth mentioning.

1 — A net clear tongue of high salinity originating from Levantine Sea, can be followed in the south of Crete Island. This tongue has a tributary going westwards in the Ionian Sea nearly parallel to 36°N towards the Sicilian Straits. In summer this westward flow seems to occur in several branches, south of 37°N. In addition, a northward tongue of IWM towards the Otranto Strait is found in the Ionian Sea near Greek side. This evidence is obvious in winter and summer, while in spring this tongue is not well presented.

2 — In the Ionian Sea the higher salinities exist in the NE, that could be explained by the influence of the Coriolis force.

C — *Mixing rations of Levantine and Adriatic water types, and the Atlantic water mass in the IWM:*

The scattering of the Θ — S points of the IWM in the Eastern Mediterranean suggests that it could be formed by mixing of Levantine and Adriatic water types as major components in addition to Atlantic water mass at the Eastern Sicilian Strait as a minor component. The relevance of each of these three constituents can be quantitatively determined by the nomogram (Fig. 6).

1 — Distributions of LWT in the core layer of IWM:

The major features of the LWT distributions are represented by figures 7 (A and B) and 8 (A and B). These figures show that the effect of the Coriolis force is well manifested by more than 50% of the LWT present in the NE of the Ionian Sea. The northward flow to Sicilian Straits are well documented

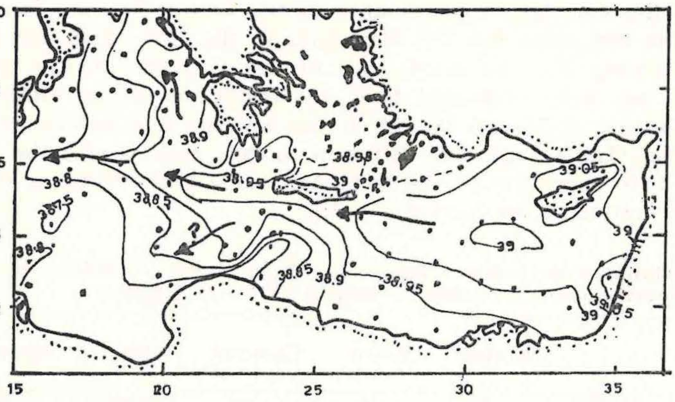

Fig. 2. Maximum salinity values in the Eastern Mediterranean in Winter.

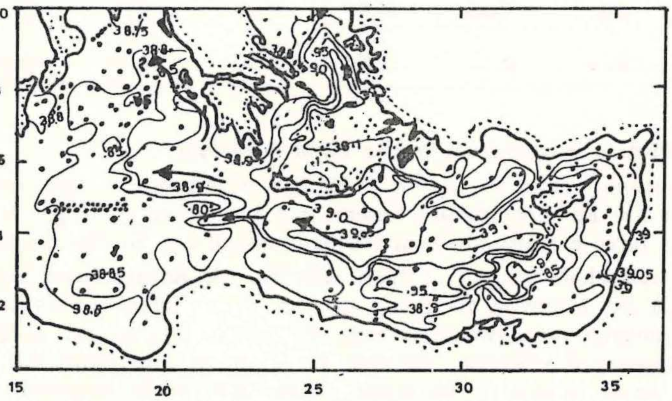

Fig. 3. Maximum salinity values in the Eastern Medierranean in Spring.

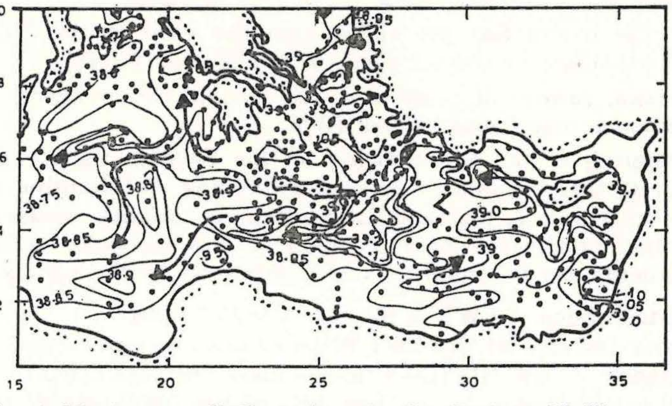

Fig. 4. Maximum salinity values in the Eastern Mediterranean in Summer.

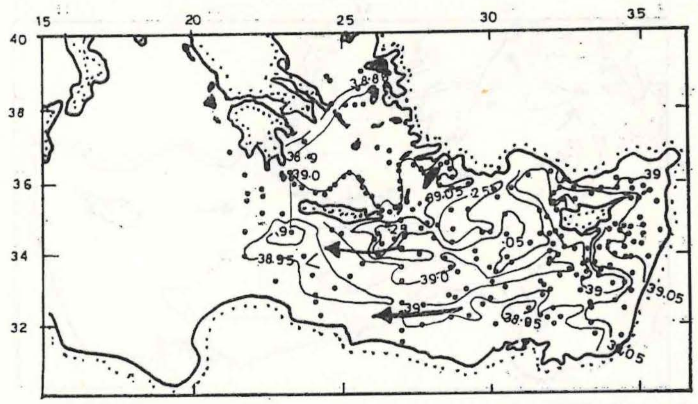

Fig. 5. Maximum salinity values in the Eastern Mediterranean in Autumn.

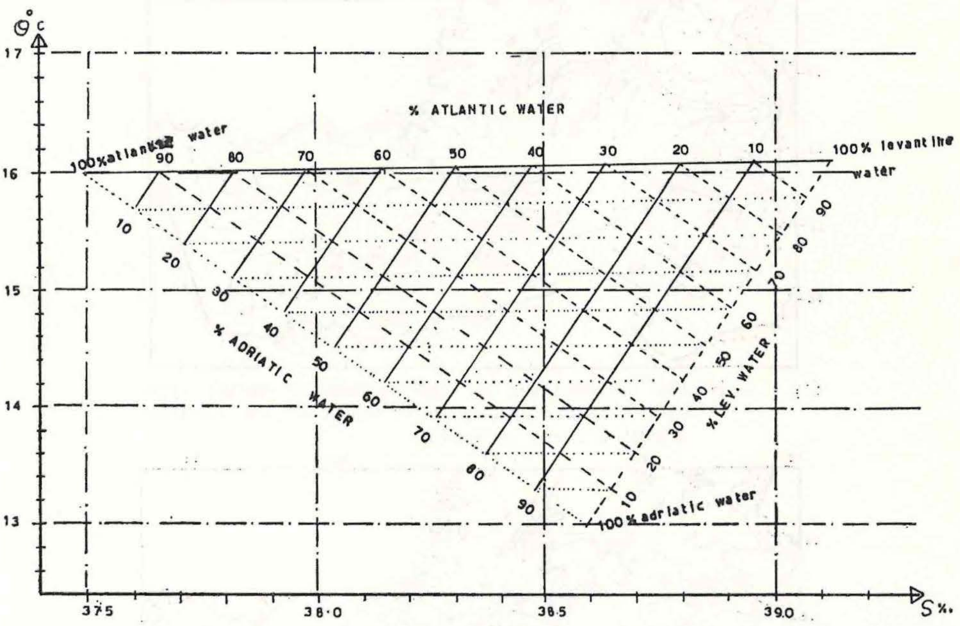

Fig. 6. A nomogram for determination of the percentages of Levantine, Adriatic and Atlantic waters in the Intermediate water mass of the Eastern Mediterranean. Lines of equal percentages are indicated by: .... ADWT, — — —

during all seasons, with a good agreement with the core salinity distributions.

2 — Distributions of the ADWT in the core laver of IWM:

This water type is coming from the Southern Adriatic Sea. Its distribution (Figs. 9 — A and B and 10 — A and B) reflects the Coriolis force influence in the Ionian Sea. The percentage of the ADWT near Otranto Strait is of about

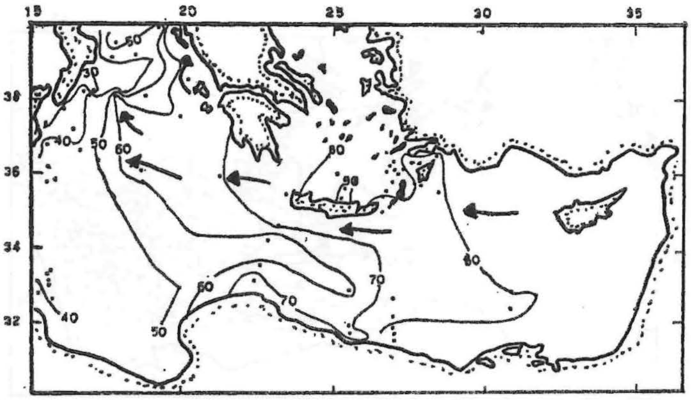

Fig. 7 — A. The percentages of the Levantine water types in the Intermediate water mass of the Eastern Mediterranean in Winter.

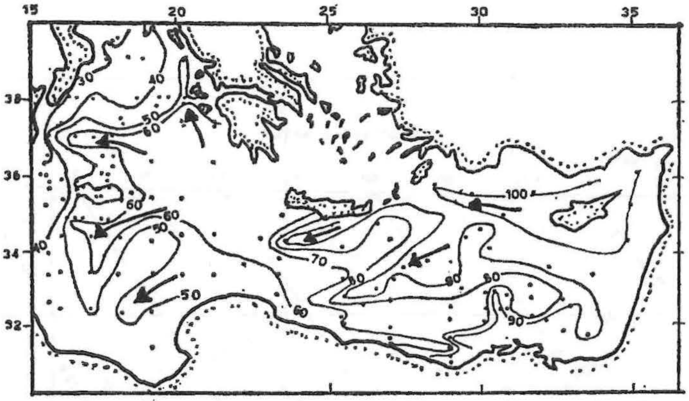

Fig. 7 — B. The percentages of the Levantine water type in the Intermediate water mass of the Eastern Mediterranean in Spring.

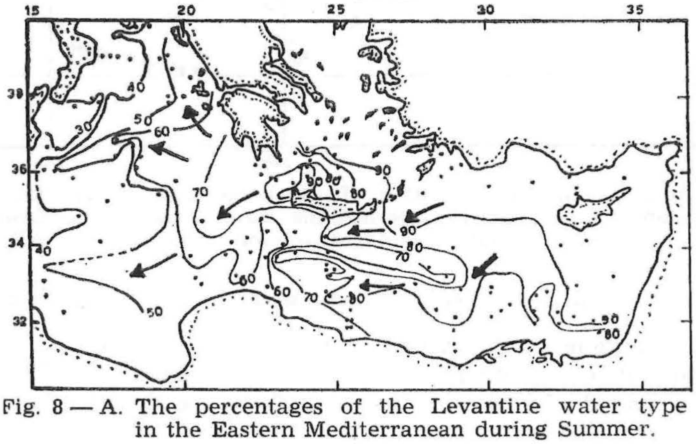

Fig. 8 — A. The percentages of the Levantine water type in the Eastern Mediterranean during Summer.

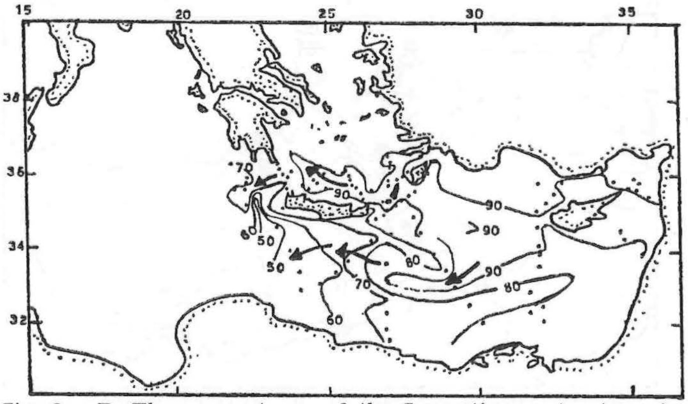

Fig. 8 — B. The percentages of the Levantine water type in the Intermediate water of the Eastern Mediterranean during Autumn.

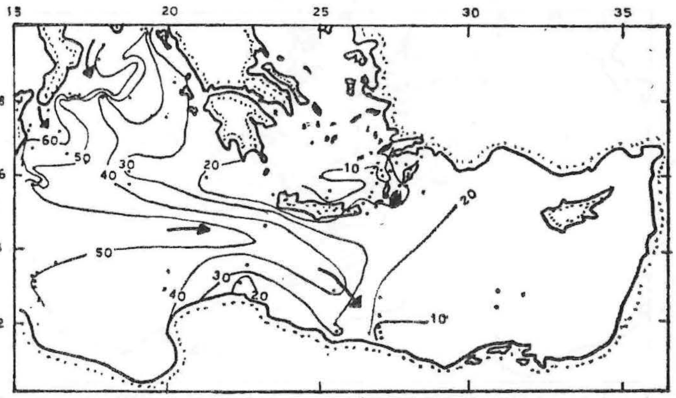

Fig. 9 — A. The percentages of the Adriatic water type in the Intermediate water of the Eastern Mediterranean during Winter.

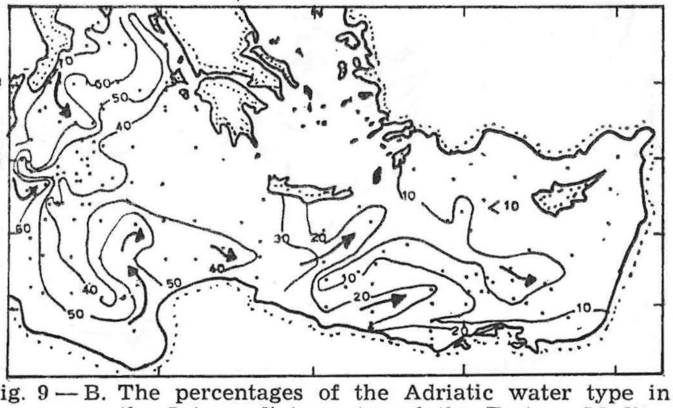

Fig. 9 — B. The percentages of the Adriatic water type in the Intermediate water of the Eastern Mediterranean during Spring.

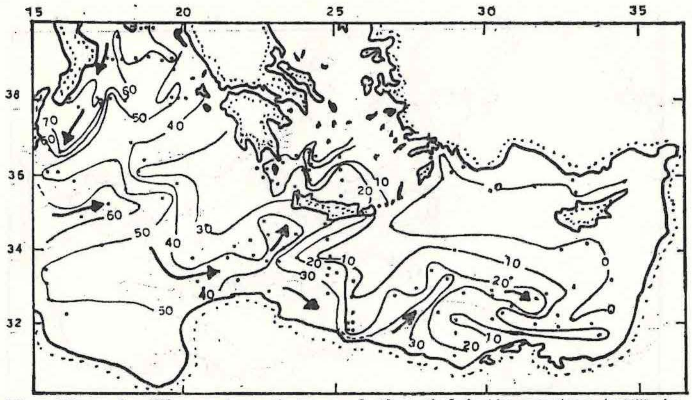

Fig. 10 — A. The percentages of the Adriatic water type in the Intermediate water of the Eastern Mediterranean during Summer.

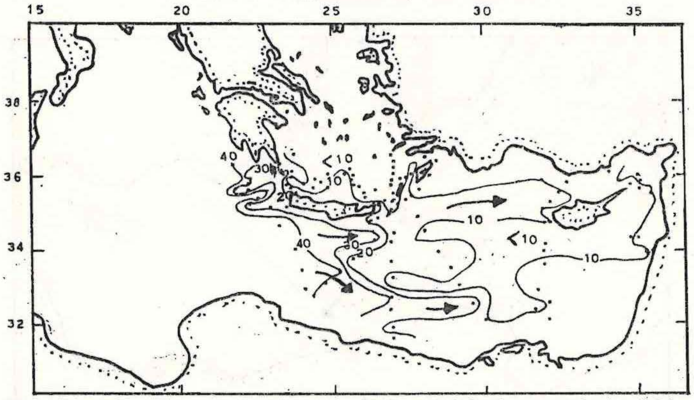

Fig. 10 — B. The percentages of the Adriatic water type in the Intermediate water of the Eastern Meditenean during Autumn.

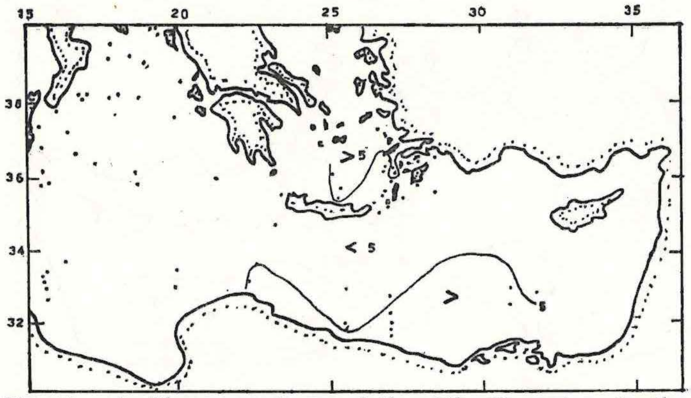

Fig. 11 — A. The percentages of the Atlantic waters in the Intermediate water of the Eastern Mediterranean during Winter.

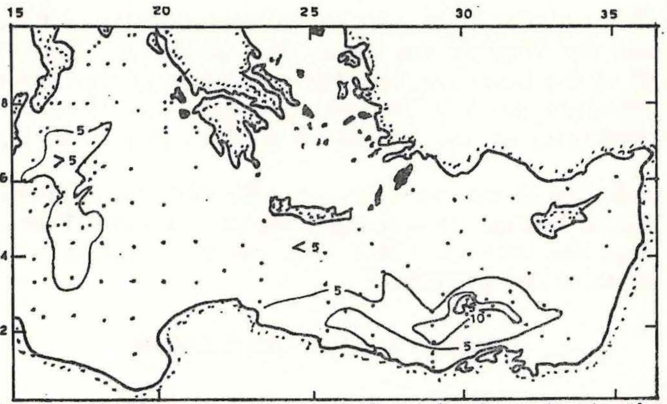

Fig. 11 — B. The percentages of the Atlantic water in the Intermediate water of the Eastern Mediterranean during Spring.

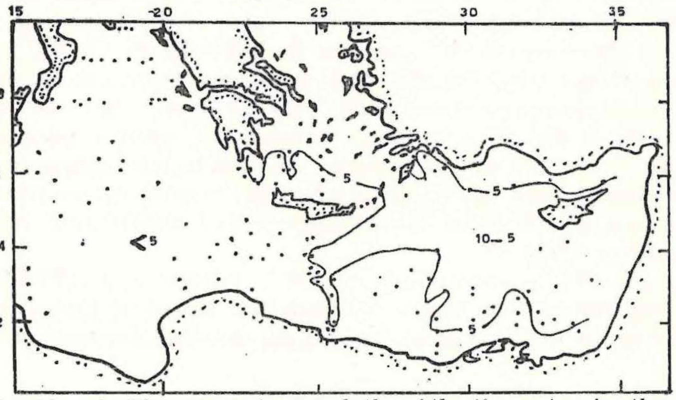

Fig. 12 — A. The percentages of the Atlantic water in the Intermediate water of the Eastern Mediterranean during Summer.

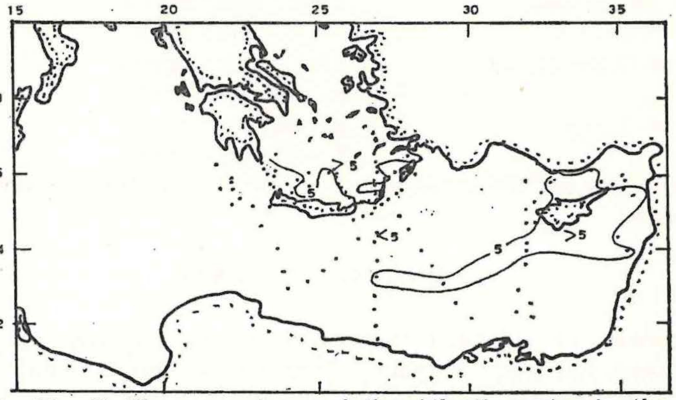

Fig. 12 — B. The percentages of the Atlantic water in the Intermediate water of the Eastern Mediterranean during Autumn.

60—70% higher concentrations near the Italian side. Its contribution can be followed along the West of the Ionian Sea, South of Ionian Sea, and the Southern part of the Levantine Sea. The percentage of this water type in the central and Northern parts of the Levantine Sea is less than 20%.

3 — Distributions of the ATWM at Sicilian Straits in the core layer of IWM:

The contribution of this water mass in the IWM has a minor importance, this can be shown by Figs. 11 — A and B and 12 — A and B. The mixing ratio of this water mass lies between 0 and 10%, except in spring when it reaches 15‰ in the South of Levantine Sea.

SUMMARY AND DISCUSSION

The westward flow of the IWM in the Eastern Mediterranean is indicated, from the horizontal distributions of the salinity maximum and the mixing ratio of the LWT, by a tongue in the Levantine Sea, south of Crete Island with branches in the central and southern parts of the Ionian Sea. The northward flow to the Adriatic Sea can also be followed in the NE of the Ionian Sea near the Greek side. On the other hand, the distributions of the mixing ratios of the second major component (ADWT) clarify that the preferred path of ADWT is from the Adriatic Sea, following the western part of the Ionian Sea, with one or two tributaries towards the East in the Levantine Sea. Finally, the Atlantic water mass has a minor role with mixing ratio of less than 15%. The asymmetric distributions of the salinity and the mixing ratios manifest the Coriolis force effect.

The ranges of the percentages of LWT, ADWT and ATWM in the NW and NE of the Ionian Sea, South of Crete and North of Egypt are shown by Table 4. The ratios in these areas have small seasonal fluctuations. The typical ranges are:

NE of Ionian Sea:	LWT	(30—50) %
	ADWT	(50—70) %
NW of Ionian Sea:	LWT	(30—50) %
	LWT	(70—90) %
South of Crete Island:	LWT	(70—00) %
	ADWT	(10—30) %
North of Egypt:	ADWT	(50—70) %
	ADWT	(30—10) %

Generally, the ATWM constitutes less than 5 % with relatively high values North of Egypt.

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Table 4, Rations of Levantine water type, Adriatic water type and Atlantic water mass (at Sicilian Straits) in the core of the Intermediate water mass in the Eastern Mediterranean.

Region	NE ION.			NW ION. SEA			SOUTH OF CRETE			NORTH OF EGYPT		
Season	LWT	ADWT	ATWM	LWT	ADTW	ATWM	LWT	ADWT	ATWM	LWT	ADWT	ATWM
Winter	60—70	30—40	≤ 5	30—40	50—60	≤ 5	60—80	20—30	≤ 5	80	<10	≤ 10
Spring	40—60	40—50	≤ 5	30—40	60—70	≤ 5	70—90	10—30	≤ 5	80	10—20	≤ 15
Summer	40—60	40—60	≤ 5	30—40	60—70	≤ 5	70—90	10—30	≤ 5	70—80	10—30	≤ 5
Autumn	—	—		—	—	—	60—80	20—40	≤ 5	70—90	10—20	≤ 5

LWT = Levantine water type

ADWT = Adriatic water type

ATWM = Atlantic water mass

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KARAKTERISTIKE, ŠIRENJE I MIJEŠANJE INTERMEDIJARNE VODENE MASE I NJENE SEZONSKE VARIJACIJE U ISTOČNOM MEDITERANU

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KRATKI SADRŽAJ

Podaci o salinitetu sa oko 2000 postaja u istočnom Sredozemlju iz razdoblja od 1948. do 1972. godine korišteni su za analizu značajki i širenja intermedijarne vodene mase koja je definirana potpovršinskim maksimumom saliniteta. Računati su omjeri miješanja glavnih komponenti koje čine tu vodenu masu. Glavni konstituenti intermedijarne vodene mase su levantinska, jadranska i u manjoj mjeri atlantska vodena masa. Omjeri miješanja su dobijeni korištenjem trokuta miješanja kao nomograma.

Raspodjela saliniteta kao i omjera miješanja levantinske vodene mase u jezgri intermedijarne vode ukazuje na širenje te vode u smjeru zapada od Levantinskog ka Jonskom moru. Pokazano je postojanje strujanja u smjeru zapada i sjevera u Jonskom moru. Strujanje prema zapadu usmjereno je ka zapadnom Sredozemlju dok strujanje prema sjeveru predstavlja transport ka Jadranskom moru. Horizontalne raspodjele saliniteta i omjera miješanja u Jonskom moru pokazuje znatne razlike između sjeveroistočnog i sjeverozapadnog dijela; u sjeverozapadnom dijelu dominira jadranska voda dok u sjeveroistočnom dominira levantinska vodena masa. Ta asimetrija ukazuje na značaj utjecaja Coriolisove sile na gibanja vodenih masa u Sredozemlju.