Qatar Univ. Sci. J (2000), 20 : 197 - 204

ON THE FORMATION OF INTERMEDIATE & DEEP WATER MASSES IN THE EASTERN MEDITERRANEAN

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تَكَوُّن المياه العميقة والبينية في شرق البحر المتوسط

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باستخدام البيانات الهيدروجرافية المستمدة من أطلس البحر المتوسط (معيزة وآخرون ١٩٩٣) بعد تنقيتها واختبارها، تمت دراسة أماكن تكون وانتشار المياه البينية والعميقة في شرق البحر المتوسط.

كانت المياه ذات الكثافة والملوحة العالية (أعلى من ٢٩) واضحة في شمال الليفانتين وبين جزيرة كريت وساحل إفريقيا في الطبقة من ٢٠٠ – ٥٠٠ متر في الشتاء، أما في الطبقة الأعمق (حتى ١٠٠٠متر) فتنتشر هذه المياه في كل الليفانتين وفي الفصول الأربعة، وبذلك يُعتبر حوض الليفانتين مكاناً لتكوّن المياه البينية والعميقة، وتنتشر تلك المياه في شمال البحر الأيوني، إلا أنها من الممكن أن تكون آتية من جنوب الأدرياتيكي.

Key Words : Eastern Mediterranean, water masses

ABSTRACT

In the eastern Mediterranean, three main water masses are classified: Modified Atlantic Water of Atlantic origin, Levantine Intermediate Water (LIW), formed in winter during storm events and Eastern Mediterranean Deep Water (EMDW). High-density water, representing the optimum value areas (> 29.0 σ_t), exists in the northern Levantine, and between Crete and African coast in the layer between 200 and 500 m in winter. In the lower layer (to 1000 m), the high-density water spreads all over the Lavantine. It is considered as a site of formation of modified Intermediate Water and deep water. The high-density water in northern Ionian may come from southern Adriatic and from the area between Crete and African coast. Deep water seems to be formed to the east of Crete Island in the northern Levantine (convection) not from the southern Agean.

INTRODUCTION

The Mediterranean Sea in one of the Atlantic Ocean adjacent seas. It is connected to the Atlantic Ocean through the narrow Gibraltar Strait. It extends between 30°15' N and 46°47' N latitudes and longitudinally from 5°21' W to 36°12' E.

The Shallow and narrow strait of Sicily (150km wide and 400m deep at the sill) divide the Mediterranean Sea into eastern and western basins. The eastern Mediterranean (Fig.1) is almost an isolated basin within which a wide range of oceanic processes are driven by all major forcing mechanisms.

Generally, water masses can be formed due to water exchange through straits, or they can be formed in definite areas, then spread as one mass with a definite physical, physiochemical and hydrological characteristics (Dobravolsky 1947).

Wüst (1961) classified four water masses in the Mediterranean Sea according to the core layer and its distribution and depending on its distribution of salinity, oxygen and temperature:

- The near-surface water of Atlantic origin, (from sea surface to about 75 m depth).
- The Intermediate water of Levantine origin (from 200 to 600 m depth).
- The deep water of northern Mediterranean regions origin (from 1500 to 3000 m depth).
- The bottom water of depth down to 4200 m

However, Moskalenko and Ovchinnkov (1965), considered the two water masses below the LIW as one deep layer.

In the Mediterranean Sea, the upper layer of Atlantic origin slowly erodes due to the net evaporation over the Mediterranean. The core of Atlantic water travels along the northern coast of Africa and through the Strait of Sicily into the eastern basin where it disappears (Robinson et Al., 1979). Except for this thin layer of diluted Atlantic water, the western Mediterranean is filled with waters of Mediterranean origin which are commonly classified into two main types: Levantine intermediate water (LIW) which originates in the eastern Mediterranean and makes up most of the Mediterranean outflow through the Strait of Gibraltar (Wüst, 1961): and western Mediterranean deep water which is formed off the south coast of France in late winter (MEDOC Group, 1970).

In the eastern Mediterranean, three main water masses are classified (Wüst, 1961; Hopkins, 1978):

- Modified Atlantic Water where fresh water of Atlantic

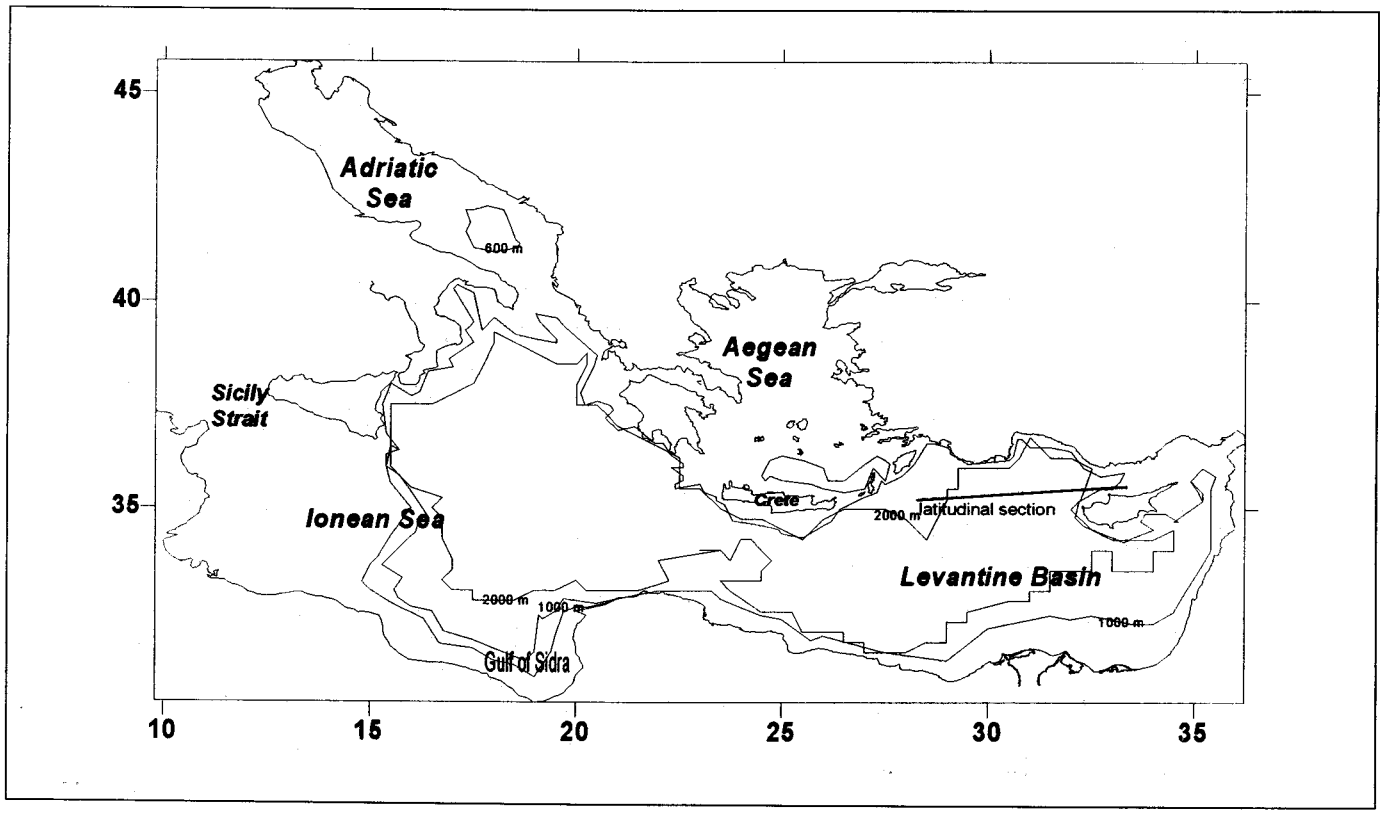

Fig. 1 : Eastern Mediterranean basin.

origin enters through the Strait of Sicily and circulates, driven by wind and other forces and becomes more saline and dense;

- LIW, formed in winter during storm events. It disperses at depths to a few hundred meters. Some LIW re-circulates within the basin and to some exists beneath the Atlantic water through the Sicily Strait; and
- Eastern Mediterranean Deep Water (EMDW), which is formed primarily in the Adriatic Sea. The site of formation of this water in winter is the southern Adriatic (POEM group, 1992). The maximum depth over the strait of Sicily is 300 m, suggesting that the deep eastern water is completely isolated from the deep western one.

1. MODIFIED ATLANTIC WATER

The second important water mass in the eastern Mediterranean is the Atlantic Water which enters through the Gibraltar Strait to balance the mass deficit of the Mediterranean. It generally hugs the north African coast (Lacombe and Tchernia, 1960, 1974; Oren, 1971) enroute to the eastern Mediterranean through the Sicily Strait (by passing the Gulf of Tunisia and the Gulf of Sidra), its salinity and depth range increases as it flows eastwards. The salinity minimum, which is the signature of this water, is found in the upper 50 m throughout the year (Manzella et Al., 1988). Its salinity increases from 37.5 psu in the Straits of Sicily to 38.6 psu near the Cretan passage where it enters the Levantine Basin. Here it is covered by surface waters of higher temperature and salinity, so its signature is a subsurface salinity minimum. Through the Strait of the Cretan Arc, modified Atlantic Water enters the Aegean Sea affecting its salt balances (Hopkins 1978), and can be detected in several regions as a subsurface (30-200 m) salinity minimum (38.68-38.90 psu).

The eastern Mediterranean, and specifically the Rhodes gyre, is the site of formation of the LIW (Ozturgut, 1976). This can be proved by the obvious difference in temperature because of the weakness of temperature gradient which can be seen at deeper depths (Moskalinko et. Al., 1976 and Maiyza, 1984, 1986). This water mass sinks to about 300 m and, following a path from the formation region to the western basin, exits from Gibraltar Strait, spreading at about 1500 m and forming the well-known salty water tongue in the Northern Atlantic.

2. LEVANTINE INTERMEDIATE WATER

One of the most important water masses found in the eastern Mediterranean is the LIW, which affects not only the entire Mediterranean, but also the Atlantic Ocean as well, (Arhan, 1987).

There is a general agreement among oceanographers that the northern part of the Levantine is the source region of the intermediate water (Nielsen, 1912; Wüst, 1959, 1960 and 1961; Lacombe & Tchernia, 1960; Miller, 1963; Ovchinnkov & Fedoseev, 1965; Moskalenko & Ovchinnkov, 1965 and Oren & Engle, 1965). This is due to the cold and dry air blowing from Asia Minor, high surface salinity in winter and the absence of subsurface minimum salinity during this season. The core of this layer lies between 200 to 250 m in summer at the northern Levantine (Nielson, 1912), between 250 to 300 m off the Egyptian coast (Maiyza, 1979 and Sharaf El-Din et Al., 1980). In the Ionian Sea it is between 250 to 400 m (Moskalinko et Al., 1976). Nittis and Lascaratos (1998) concluded that under mean climatological conditions the LIW is formed during winter in the Rhodes cyclonic gyre. Haines and Wu (1998) showed that baroclinic eddies are critical to the effective dispersal of the LIW throughout the eastern Mediterranean basin. The LIW enters the Adriatic basin and pre-conditions deep water formation which would not otherwise occur due to low surface salinity in winter.

Depending on the hydrographic data of the climatological atlas of the Meditteranean Sea, (Maiyza et. Al., 1993), the water density was calculated using the hydrographica table (UNESCO, 1987), from which the density values of ≥ 29.0 where plotted at different levels representing the intermediate level (Fig. 2), and the upper limit of the deep layer.

From these figures the areas of high density water (>29.0 σ_t), at the same level can be seen in the northern Levantine, and between Crete Island and African coast in the layer between 200 & 500 m in winter (Fig. 2). In the lower layer (to 1000 m) the high density water spreads all over the Levantine in the four seasons. It is obvious also that the southern Adriatic has high density water which leads to be considered as a site of formation of modified Intermediate Water and deep water. The deeper high density water areas (600 – 1000 m) are shown in Figure (2). It is obvious that, it is found in northern Ionian, which may come from southern Adriatic and from the area between Crete and African coast.

The LIW is the saltiest water mass of the Mediterranean

and is generated in several areas of the Levantine Basin and in the south Aegean Sea in February and March under the influence of dry, cold continental air masses (Morcos, 1972; Ozturgut, 1976; Georgopoulos et Al., 1989; Theocharis et Al., 1988). Its signature is a maximum in salinity found in the sub-surface layer during the spreading phase. Its enters the Aegean Sea through the Straits of the Cretan Arc. Its typical core values at the sill depths are 14.5°C in temperature and 38.9 psu in salinity, at σ_t=29.1 surface. The LIW overlies the colder and saline EMDW. The layer between 700 and 1600 m is a transitional water mass lying between the LIW and EMDW, which is considerably uniform, with values of 13.6°C for temperature and 38.7 psu for salinity.

3. DEEP WATER

The origin and formation of the EMDW are poorly understood. Nielson (1912) has shown dominance of the Adriatic and Agean seas as source areas for the deep and bottom water of the eastern Mediterranean. Pollak (1951) excluded the sharing of Cretan Sea in the formation of deep water depending on hydrochemical analysis. Wüst (1961) noticed the effect of the Agean Sea in the formation of deep water depending on the water tongue of high oxygen content and lower temperature of the east of Crete (Fig.3) where its value was more than 4.2 ml/l at 2000 m depth. Moskilanko et. Al., (1976), suggested that the deep water flows from the Cretan Sea (southern Agean) to the eastern Mediterranean through the Antekithra and Kassos straits. Klein, et. Al., (1999) proposed a new deep water mass named Cretan Sea Overflow Water (CSOW). It is warmer (θ =13.6°C) and more saline (*38.80 psu*) than the previously dominating EMDW, causing temperatures and salinities to rise towards the bottom. Outside the Aegean the upwelling of mid-depth waters reaches depths shallow enough so that these waters are advected into the Aegean and form a mid-depth salinity-minimum layer.

All the previous results can be achieved if only that the deep water to be formed to the east of Crete in the northern Levantine (convection) and not advected from the southern Agean. The formation of deep water in this area was first considered by Maiyza (1984). He cleared that the temperature, salinity and density at the surface change from year to year at

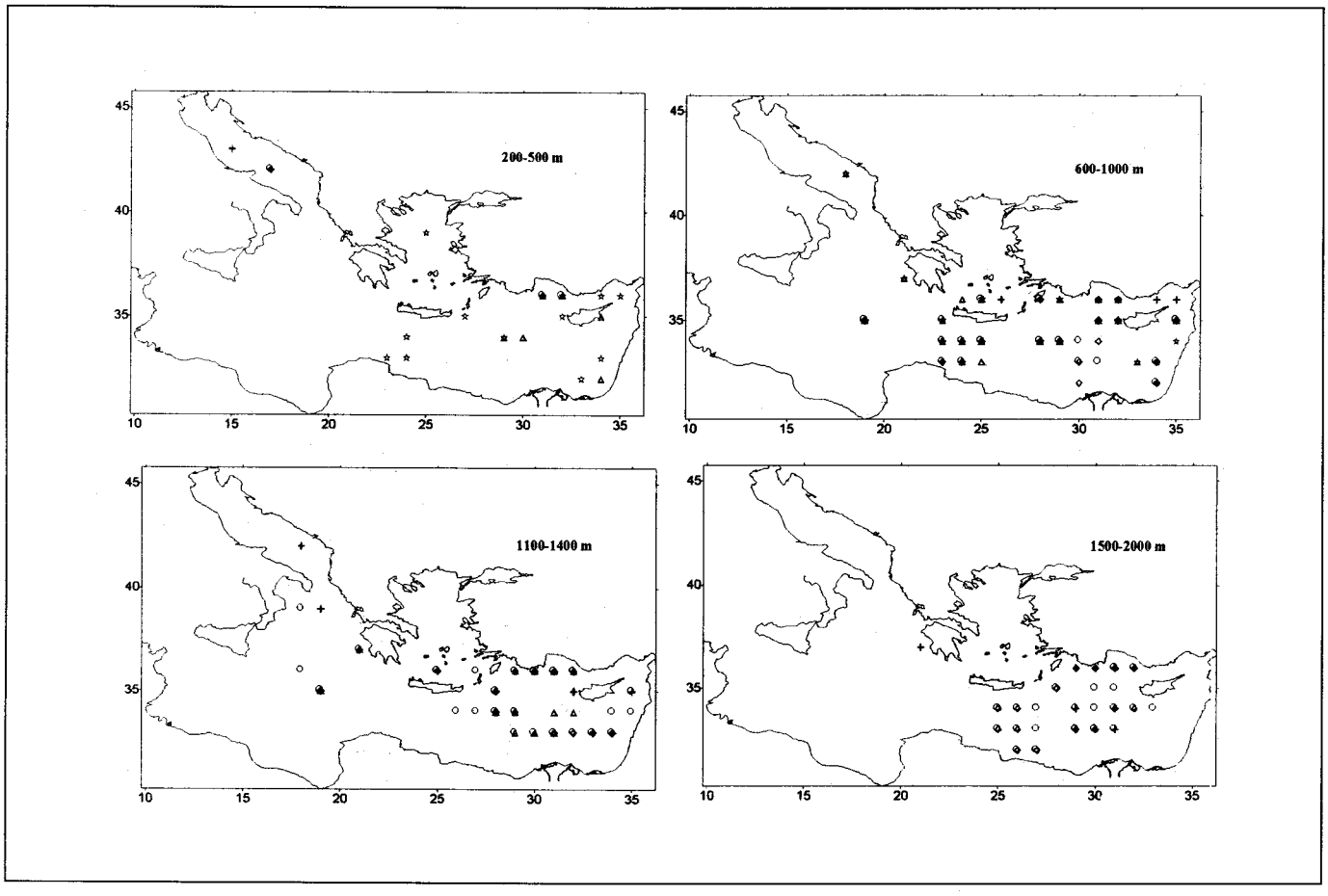

Fig. 2 : Areas of high water density (> 29.0 σ_t) in winter

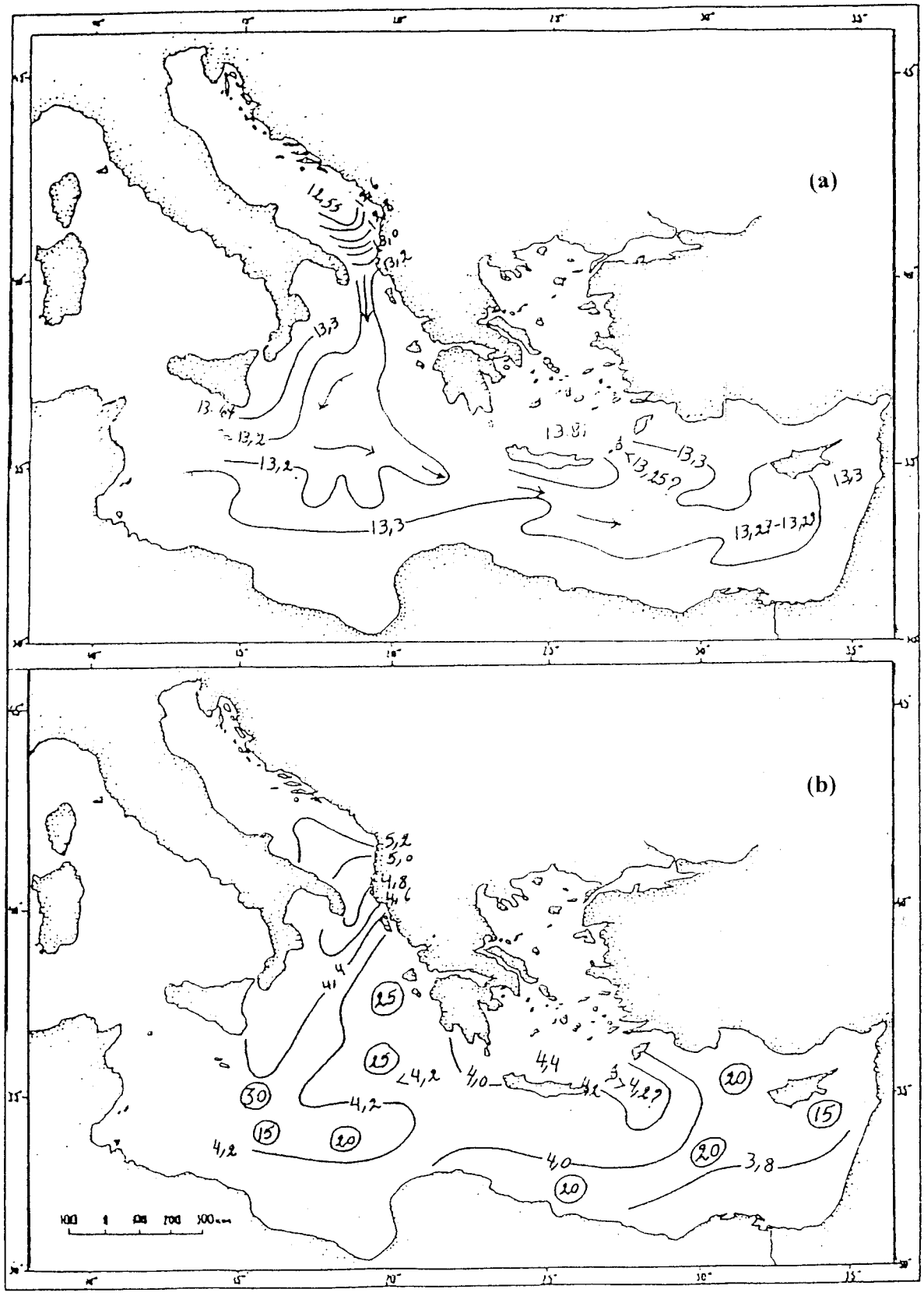

Fig. 3 : Horizontal distribution of potential temperature (a) and dissolved oxygen content (b) at the core of deep-water mass, Eastern MediterraneanSea, (after Wüst, 1961).

(20) = 2000 m depth

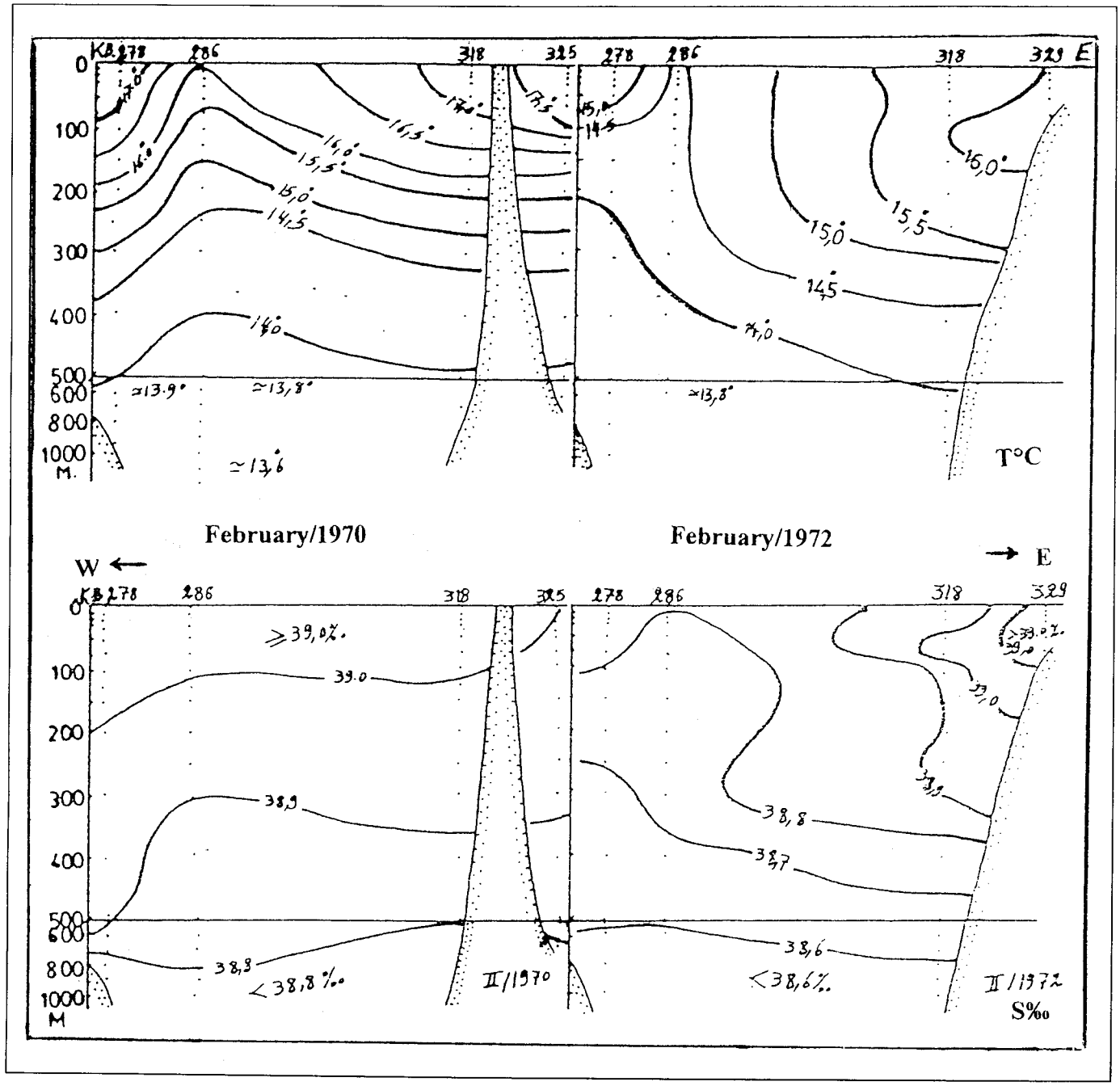

Fig. 4 : Vertical distribution of water temperature (up) and salinity (down) in warm (left) and cold (right) winters, along a latidinal section in the north Levantine basin, - ref. Fig.1- (after Maiyza, 1984).

the same place and same month. Thus the deep water does not always have the same hydrographic characteristics due to the difference of the years of formation. So he assumed in his work that this area is a source of formation of deep water in the warm years under the highest salinity condition due to evaporation while in the cold years under the lower temperature condition. Difference in hydrographic characteristics between the warm and cold winters are shown in Figure 4, from which one can notice that the hydrographic differences can be recognized at deep levels between the cold and warm winters.

CONCLUSION

The main water masses in the eastern Mediterranean are: The surface and subsurface waters of Atlantic origin, The LIW of Levantine origin. It exists in the northern Levantine, and between Crete and African coast in the layer between from 200 to 500 m in winter. The southern Adriatic is considered as a site formation of modified Intermediate Water and deep water.

Deep water, might be formed to the east of Crete in the northern Levantine (convection) not from the southern Agean. High

density water in northern Ionian, may come from southern Adriatic and from the area between Crete and African coast.

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