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## TRACE ELEMENTS IN ATMOSPHERIC PARTICULATES OVER THE EASTERN MEDITERRANEAN; CONCENTRATIONS, SOURCES, AND TEMPORAL VARIABILITY

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**Abstract**—The first long-term, land-based sampling of the atmosphere above the Turkish coast of the Northeastern Mediterranean Sea ( $36^{\circ} 33' 54''$  N and  $34^{\circ} 15' 18''$  E) has demonstrated the dominance of Sahara desert particles over the basin. Atmospheric samples, collected on Whatman-41 filter papers, had been analyzed for Al, Fe, Ca, Mg, Mn, Ni, Cr, Co, Cd, Pb, Zn, V and Na by flame and flameless modes of AAS. Analysis of 339 samples collected during the period August 1991 to December 1992 has shown that pulses of desert particles invade the region from March–May and October–November and during such events the concentrations of the crustal elements (Al, Fe) in atmospheric particulate increase by an order of magnitude. The concentrations of such anthropogenic elements as Zn and Cd reach their maximum levels during the dry season. Three days backward, three-dimensional air-mass trajectory analysis has confirmed the invasion of the basin by sporadic but intense concentrations of dust originating from the Sahara. The elemental composition of size fractionated samples collected over the basin in summer and fall also verifies the existence of particles of both anthropogenic and crustal origins. The geographic position of the sampling tower lies downstream of the tracks of all major air masses affecting the area and therefore the data set can be used to define the atmospheric particulate over the Eastern Mediterranean.

*Key word index:* Mediterranean, trace elements, Sahara, crustal, anthropogenic, trajectories.

### INTRODUCTION

Worldwide studies have shown that the transport of atmospheric particulate matter and its associated trace elements is of greater biogeochemical consequence than was originally thought. The impact of atmospheric iron on phytoplankton production and the resulting increase in biomass, as initially proposed by Martin and Fitzwater (1988), Martin *et al.* (1990) and Donaghay *et al.* (1991) is now proven through the *in situ* experiment, "Iron Ex1", carried out in the Pacific Ocean in November 1993 (Wells, 1994). Further, Zhuang *et al.* (1992) have established that, during the long-range transport of mineral aerosols from arid regions to the atmosphere of the open oceans, Fe(III) can be reduced to Fe(II). They hypothesized that the rapid dissolution of Fe(II) formed by photoreduction could enhance biological activity in the marine environment and thereby result in an increase in the dimethyl sulfide (DMS) concentration in the atmosphere.

Wide variation in the trace metal concentrations found in atmospheric particulate sampled daily both at a remote Western Mediterranean coastal station

(Bergametti *et al.*, 1989) and on board ship (Dulac *et al.*, 1987) have highlighted the importance the Co-ordinated Mediterranean Research and Monitoring Program (MEDPOL) attached to a continuous sampling strategy for assessing the inputs of trace elements over the Mediterranean basin (UNEP, 1989, 1992). Such sampling has been undertaken by institutions along the Western Basin at various land-based stations. Yet, apart from dust pulse episodes sampled by the Israeli scientists Yaloon and Ganor (1979) and the shipboard samples collected by Chester *et al.* (1981), no land-based atmospheric sampling of the Eastern Basin has been reported.

The most comprehensive study carried out in the Mediterranean Sea has been realized within the context of EROS 2000 (European River Ocean System). This study, confined to the Western Basin, concluded that the atmospheric input of material to the basin is as important as the riverine input (Martin *et al.*, 1989). The damming of the Nile, previously the major source of particulate matter to the Eastern Basin, has left the Seyhan, Ceyhan and Manavgat located along southern Turkey as the only riverine sources of material to the Eastern Basin.

These inputs will be reduced as the rivers are used as fresh water supplies to the Middle East states; indeed, construction has already started to transport

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Manavgat water by tankers to Israel. Eventually, therefore, only the atmospheric input to the Eastern Basin will remain to act on the biogeochemistry of the basin, together, of course, with the oceanographic processes. These emphasize the importance of possessing knowledge of the long-term variations in the atmospheric concentrations of those trace elements known to affect biogeochemical processes directly. Recently, Gilman and Garrett (1994), describing the involvement of the attenuation of short-wave radiation by aerosols in the Mediterranean heat budget, have stressed the importance of the radiative forcing by mineral aerosols being a function of time and space. Their work has shown that allowance for the seasonal variability of aerosols over the Mediterranean, rather than employing a constant aerosol attenuation factor, improves the calculation of the radiation budget of the Mediterranean.

For all these reasons, the first results presented here of atmospheric particulate sampling over the Eastern Mediterranean should be invaluable to the oceanographic community.

#### MATERIALS AND METHODS

The atmospheric sampling tower constructed from the skeletons of two 20 ft commercial containers are located at the harbor jetty of the institute in Erdemli (36° 33' 54" N and 34° 15' 18" E). Its vicinity is surrounded mainly by lemon trees and cultivated land and greenhouses. Populations of 55,000 and 500,000 inhabitants live 7 and 45 km to the east of the tower, respectively. Pulp and paper industry exist 45 km to the west of the tower and a petroleum refinery, soda, chromium, fertilizer industries and a thermic power plant are located 45 km east of the sampling tower.

In this study two different kinds of sample collection systems were utilized. For the collection of the total size spectrum of the particles a model GMWL-2000 (General Metal Works Inc., OH) hi-vol, 1 m<sup>3</sup> min<sup>-1</sup>, pump was used. Size separated atmospheric particulate samples were collected by a model GUV-15H cascade impactor from the same manufacturer. The cascade impactor possesses a size selective inlet that removes particles > 10 μm and it is equipped with a Model 350 electronic flow controller to maintain a constant flow (0.6 m<sup>3</sup> min<sup>-1</sup>) through the impactor. At this flow rate the particle cut-off diameters range from 7 and < 1.1 μm diameter. The two sampling systems had been run simultaneously and elemental compositions of particles larger than 10 μm were obtained by subtracting the total concentrations measured at the cascade impactor filters from the total concentrations of the elements measured in the samples collected by the hi-vol pump. Flow rates had been monitored by a calibration kit (model PN G25) provided by the manufacturer. Whatman 41 (20.3 × 25.4 cm) filters (Whatman Int. Ltd, U.K.) were used for collecting samples by the hi-vol pump. Four perforated, disc-shaped and one rectangular shaped, back up Whatman 41 filters were used in the cascade impactor. Sampling durations were 24–72 h and about 10 d in the hi-vol sampler and the cascade impactor, respectively. To minimize contamination, filters were always manipulated in a clean, laminar-flow bench with the use of Teflon-coated forceps and disposable nylon gloves. Blanks were obtained at regular intervals by placing the filters inside the filter holder when no air was drawn through them. Before and after sampling, samples and blank filters were stored in polyethylene bags until analysis. One-quarter of each filter was cut off and placed in a PTFE beaker,

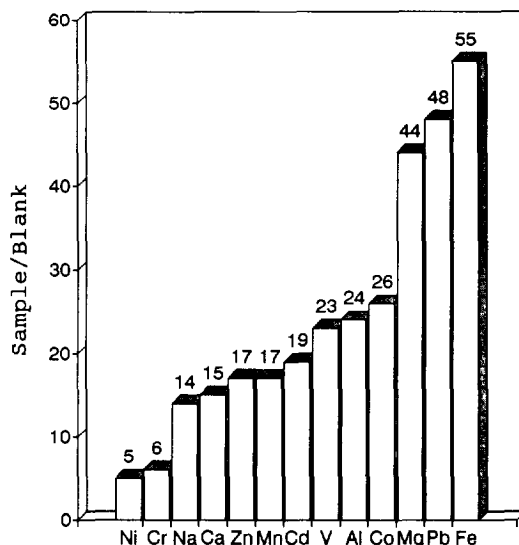


Fig. 1. Sample-to-blank ratios of the elemental concentrations in Whatman 41 filter papers.

digested with HF/HNO<sub>3</sub> acid mixture at 120°C and subsequently made up to 25 ml volume with 0.1 N HNO<sub>3</sub>. Milli-Q double-distilled water (DDW) was used throughout the analysis. Digested samples were analyzed for their trace metal contents by a computer-controlled GBC-906 model (GBC Scientific Equipment Pty Ltd, Australia) atomic absorption spectrometer (AAS) equipped with a deuterium lamp. Both flame and flameless modes of the AAS were utilized with the attachment of FS3000 and PAL3000 autosamplers, respectively.

To assess the blank contributions, the blank-to-sample ratios for each element were calculated. Results are given in Fig. 1. It can be seen that the contribution from Whatman 41 filter papers was significant only for Ni (20%) and Cr (17%). For the other elements the subtracted blank values were less than 10% of the mean concentrations of the elements throughout the 17 months collection period at Erdemli. The elemental concentrations of atmospheric particulate over the Eastern Mediterranean being relatively high, the subtraction of the blanks both from the hi-vol and cascade samples did not contribute significantly to uncertainties in final concentrations.

The accuracy of the analytical technique was tested by analyzing Community Bureau of Reference (BCR)—Brussels, standard reference material light sandy soil (CRM 112). The analytical precision was approximately 5% for Al, 4% for Fe, 2% for Mn, 6% for Cr, 6% for Ni, 3% for Zn, 5% for Pb, 5% for Cd, 8% for V, 7% for Co, 5% for Na, 6% for Ca and 7% for Mg.

Air parcels backtrajectory analysis was evaluated as a tool to detect remote sources of the atmospheric particles over the Eastern Mediterranean. The operational trajectory model developed by the European Center for Medium-Range Weather Forecasts (ECMWF) center in Reading, U.K. was applied to three-dimensional analyzed wind fields acquired from the archive of ECMWF. Three days backward calculations were performed starting at midday (12 00 UT) and arriving at the collection point at 850 and 500 hPa barometric levels.

#### RESULTS AND DISCUSSIONS

Table 1 summarizes the statistics of the elemental concentrations (corrected for blanks) of a total of 339

atmospheric particulate samples collected at Erdemli from August 1991 to December 1992. The concentration ranges for each element presented in Table 1 are very high, thus suggesting significant temporal variations in the concentrations. Before attempting to explain the variability of each trace element, one compares the results summarized in Table 1 with comparable atmospheric sampling programs carried out over the Mediterranean basin in order to see the effect of geographic position on the trace metal composition of the aerosols in the coastal Mediterranean atmosphere. Table 2 compares the geometric mean concentrations of the elements in atmospheric particulate collected both from different land-based stations and on board ship throughout different cruises along a Mediterranean transect. The locations of the land-based stations are depicted in Fig. 2. Table 2 demonstrates that the major difference in the composition of atmospheric particulate observed in this study and

those located in the Western Basin is that particulate from the Eastern Basin had higher concentrations of crustal elements, specifically, Al and Fe and lower mean concentrations of anthropogenic elements, specifically, Cd, Zn, Pb. Although the concentrations of such crustal elements as Al and Fe were about twice as high as at western stations the concentration of Mn was comparable for both basins. This element has a mixed origin; its concentration was affected by both crustal and anthropogenic sources. To estimate the relative importance of each type of source to the Mn concentration over the Eastern Mediterranean, the excess Mn ( $Mn_{ex}$ ) concentration was calculated utilizing crustal ratios of the elements reported by Taylor (1964).  $Mn_{ex}$  was calculated for each sample according to the equation

$$Mn_{ex} = Mn - \left( Al \left( \frac{Mn}{Al} \right)_{crust} \right)$$

where Al and Mn refer to the concentration of the elements measured in atmospheric particulate. About 20% of the total samples collected during this study contained no noncrustal Mn. The remaining samples had about 30% of their total Mn concentration as  $Mn_{ex}$ .

Lower Pb concentrations (Table 2) were reported for the Mediterranean Sea (Chester *et al.*, 1993) and Corsica (Bergametti *et al.*, 1989) than for other coastal stations suggesting local traffic emissions to be much more pronounced at the latter stations. Table 2 shows that the elemental compositions obtained throughout the Mediterranean transect resemble those in the Eastern Basin with the exception of Cr, Ni and Pb. The observations of low concentrations, compared to those observed at land-based stations in the Western Basin, of such elements as Pb, Cd and Zn show the effect of anthropogenic emissions over the Eastern

Table 1. Summary statistics of the elemental concentrations for the whole sampling period at Erdemli station (339 samples).

Element	Geo. mean	SD	Range
Al	685	3.1	21–22,560
Fe	685	2.9	35–30,390
Ca	3140	2.5	230–52,840
Mg	1200	2.3	70–16,750
Na	1900	3.1	45–44,960
Mn	12.6	2.7	1.0–305
Ni	5.6	2.2	0.1–56
Cr	8.5	2.5	0.1–66
Co	0.40	3.19	0.01–11.2
Cd	0.19	2.59	0.01–3.7
V	7.7	2.2	0.29–123
Zn	19	2.4	1–206
Pb	30	2.8	1.4–730

Note: Concentrations are given in  $ng\ m^{-3}$  of air.

Table 2. Variations in the concentrations of trace metals in the atmospheric particulate over the Western and Eastern Mediterranean (sampling locations are depicted in Fig. 2)

Element	Erdemli <sup>a</sup>	Blanes <sup>b</sup>	Cap Ferrat <sup>c</sup>	Tour du Valat <sup>d</sup>	Corsica <sup>e</sup>	Mediterranean Sea <sup>f</sup>
Al	685	390	370	380	168	936
Fe	685	316	320	275	144	707
Mn	12.6	10	11	13	5.3	16
Ni	5.6	5.5	2.8	—	—	4.2
Cr	8.5	1.8	2.5	—	—	3.1
Co	0.40	0.20	—	—	—	—
Cd	0.19	0.60	0.36	0.51	—	0.17
V	7.7	—	—	—	—	—
Zn	19	50	41	60	19	12
Pb	30	50	58	56	16	10.5

Note: Concentrations are given in  $ng\ m^{-3}$  of air. (—) indicates no data reported.

<sup>a</sup>Present study.

<sup>b</sup>Chester *et al.* (1991).

<sup>c</sup>Chester *et al.* (1990).

<sup>d</sup>Guieu (1991).

<sup>e</sup>Bergametti *et al.* (1989).

<sup>f</sup>Chester *et al.* (1993).

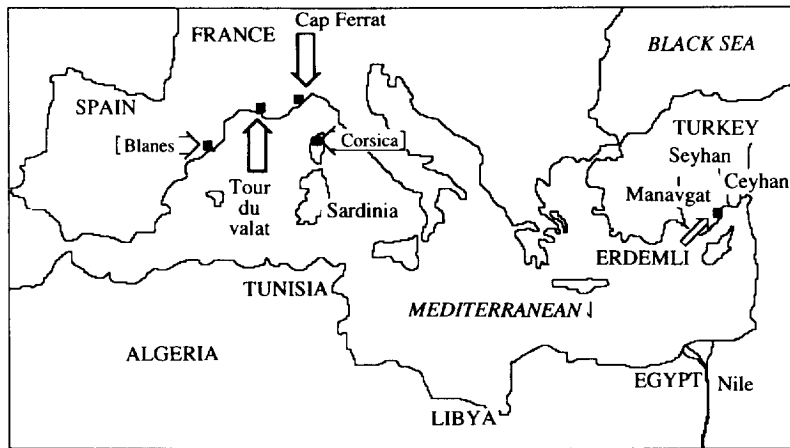


Fig. 2. Location of the land-based atmospheric sampling stations at the Mediterranean basin.

Basin to be much less pronounced. This can be explained simply by the presence of industrialized nations that define the northern border of the Western Basin. In contrast the Eastern Basin is bounded by a desert belt to the south and east and semi-industrialized and agricultural countries to the north.

The observation of high Cr and Ni levels over the Eastern Basin is probably due to the presence of ophiolitic rocks that frequently outcrop on the coastal hinterland of the basin and are relatively enriched with Cr and Ni bearing minerals (Aslaner, 1973; Tolun and Pamir, 1975). Guerzoni *et al.* (1989) similarly explained the enrichment of Adriatic samples in Ni and Cr as arising from ophiolitic minerals in the Balkan area. The geochemical characteristics, the depositional environment and the provenance of surface sediments from the Cilicia Basin (the area between Cyprus and southern Turkey) have been well described by Shaw and Bush (1978). The enrichment of the near shore sediments in Cr and Ni was attributed to the terrestrial geology and river drainage. A significantly high Cr content in one sediment sample was explained as due to the existence of major chromite deposits in the central part of the Taurus Mountains flanking the coast. The enrichment of the basin sediments in Cr and Ni can be shown by comparing their element/Al ratio with the same ratio in the crust. The Cr/Al and Ni/Al ratios in the crust are 0.001 and 0.001, respectively (Taylor, 1964), whereas the mean ratios for the basin sediments were 0.007 and 0.004 (Shaw and Bush, 1978). The mean ratios for the same elements in atmospheric particulate are 0.012 and 0.008, respectively (calculated from Table 1). The slightly higher ratios in the atmospheric particulate compared to basin sediments may be attributed to local anthropogenic emissions.

Figures 3a–d show the daily variation in the concentrations of Al and Fe, and Cd and Zn in atmospheric particulates collected between August 1991 and December 1992, thus illustrating the variations in

crustal and anthropogenic components. The figures also depict local rainfall, showing scavenging of precipitation to be effective in winter, spring and autumn but not during summer, which is a dry period. The temporal variations in the concentrations of the crustal elements, Al and Fe are well correlated, indicating a common source for these elements. The linear correlation coefficient of  $r = 0.88$  ( $p < 0.01$ ) confirms the highly significant relation between these two elements. The most remarkable feature of the entire sampling period was the marked but sporadic increase in the concentrations of both Al and Fe during the course of the transitional months (March, April, May, October and November), geometric mean concentrations being  $850$  and  $830 \text{ ng m}^{-3}$  for Al and Fe, respectively. Alpert *et al.* (1990) explained this as being due to the approach of inter monthly cyclonic routes towards the African coast during March. These become more pronounced in April when most cyclones move along the North African coast sweeping through the sources of mineral aerosol and consequently carrying abnormal concentrations of Al and Fe over the sampling region. The variations in the composition of atmospheric particulate over the Eastern Basin during this period were entirely governed by the approach of cyclones and their associated fronts that, most of the time were coupled to rains and followed by strong northerly, cool and dry winds. In this study, the sporadic pulses originating from the Sahara and Middle East deserts as a result of the synoptic scale fronts have been detected by coupling the behavior of the geochemical tracers (Al and Fe) with the air mass back-trajectories throughout the March–May and October–November periods. Previously, the long-range transport of desert dust has been verified utilizing the same method as that used in this study together with satellite data in the western part of the Mediterranean Sea (Martin *et al.*, 1990; Dulac *et al.*, 1992). One may note from Figs 3a and b that the minimum concentrations of Al and Fe observed between sporadic events

were similar to the concentrations observed during winter. This behavior is confirmed by the three-dimensional air mass backtrajectory analysis showing the path of the pulse of a dust event observed over the basin during 18–22 April 1992 (Figs 4a–c). On 18 April (Fig. 4a), the air mass arriving at 850 hPa originated from within Turkey, whereas the air mass at 500 hPa was from the Sahara. The elemental compositions were Al 200, Fe 240, Cd 0.16 and Zn 22.6  $\text{ng m}^{-3}$ . On 19–20 and 21 April 1992 the trajectories reaching the sampling point at Erdemli had all passed over the Sahara both at the 850 and 500 hPa levels (Fig. 4b represents the situation for 21 April) and the Al and Fe concentrations increased to peak

levels of 9860 and 4855  $\text{ng m}^{-3}$ , whereas Cd and Zn decreased to 0.04 and 13.2  $\text{ng m}^{-3}$ , respectively. On 22 April, the air mass trajectories originated from the N–NW directions (Fig. 4c) and the Al and Fe concentrations decreased to 600 and 575  $\text{ng m}^{-3}$  levels and Cd and Zn levels increased to 0.31 and 17.7  $\text{ng m}^{-3}$ , respectively. Thus, the large variability in the elemental concentrations was entirely dependent on the source strength and airflow pattern.

June, July, August and September can be designated as the dry season of the Eastern Basin that is reflected by the near uniform geometric mean concentrations of Al and Fe in the atmospheric particulate, 1120 and 1140  $\text{ng m}^{-3}$ , respectively. Alpert *et al.*

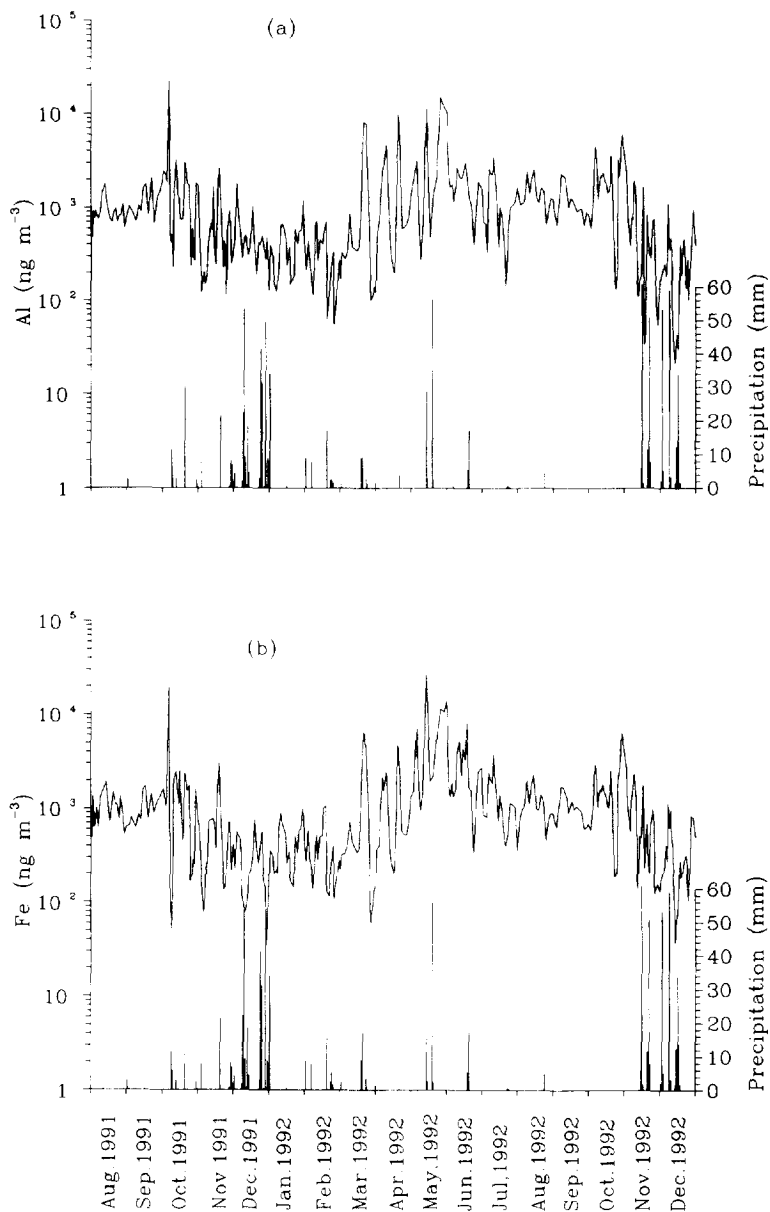


Fig. 3a and b.

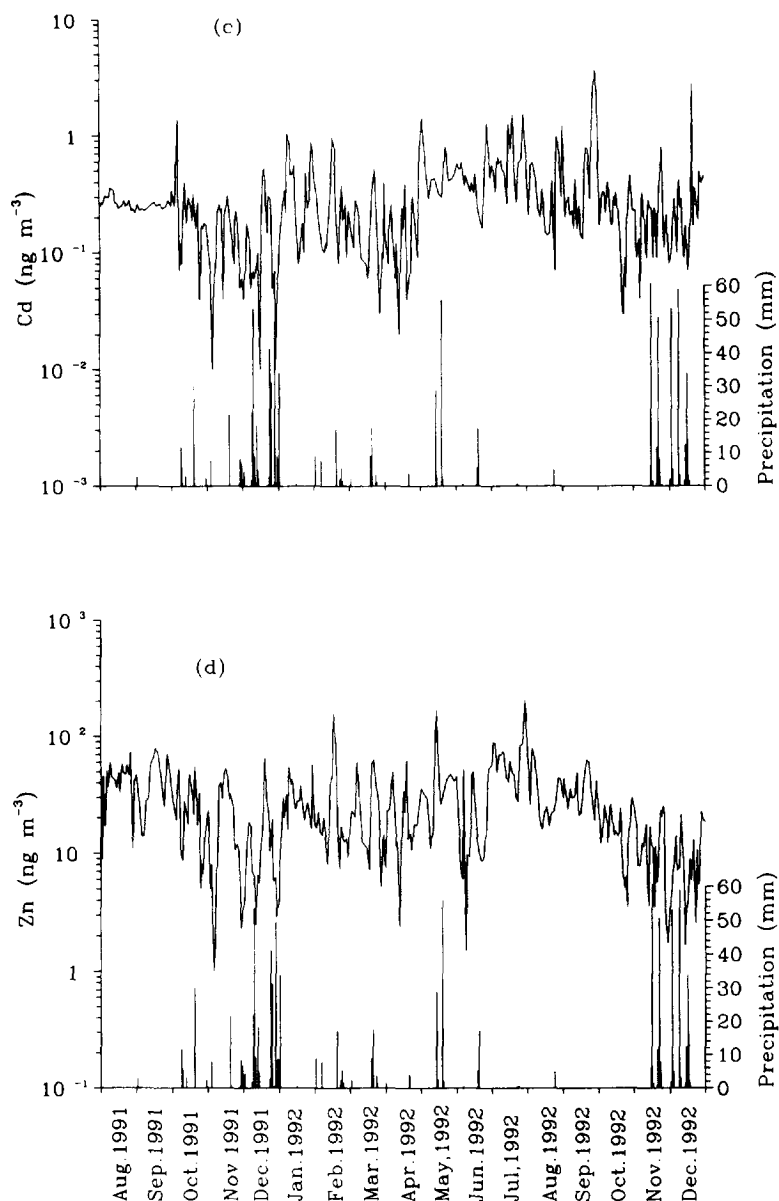


Fig. 3. Daily variation in the atmospheric concentrations of: (a) Al; (b) Fe; (c) Cd; (d) Zn. The amount of the local precipitation is reported at the bottom of the figure.

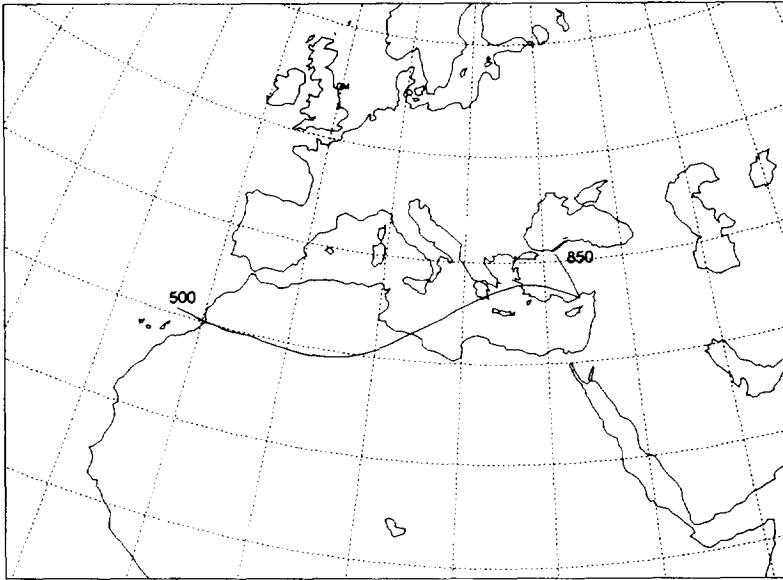
(1990) have demonstrated that the central and Eastern Basin is dominated by a region of subtropical high pressure and any cyclones that form tend to be non-migratory. During the dry summer season the effect of local precipitation scavenging is minimum, limited to rare showers (Fig. 3). A five years climatological study of airflows (1978–1982) in Israel by Dayan (1986) indicates seasonal variation in the frequency of airflow patterns at the 850 hPa barometric level. According to his conclusions, the long-range transports of desert dust to the eastern Mediterranean from North Africa and from the Middle East deserts occur in spring and fall, respectively. Our results have shown that this

mode of transport can be seen at 500 hPa levels in summer time, also. Figure 5a depicts some selected events showing the types of flow originating from North Africa at the 500 hPa level in summer and the corresponding trajectories at the 850 hPa level are given in Fig. 5b. Figure 6 shows that the geometric means of all the elements (except Cr and Pb) in summer exhibit higher values with respect to winter and transitional seasons. Dayan and Miller (1989) have explained that, in summer time, there exist finite temperature inversions that are well correlated with the depth of the mixing layer and restrict vertical mixing. The land–sea cooling cycle in this season results in the

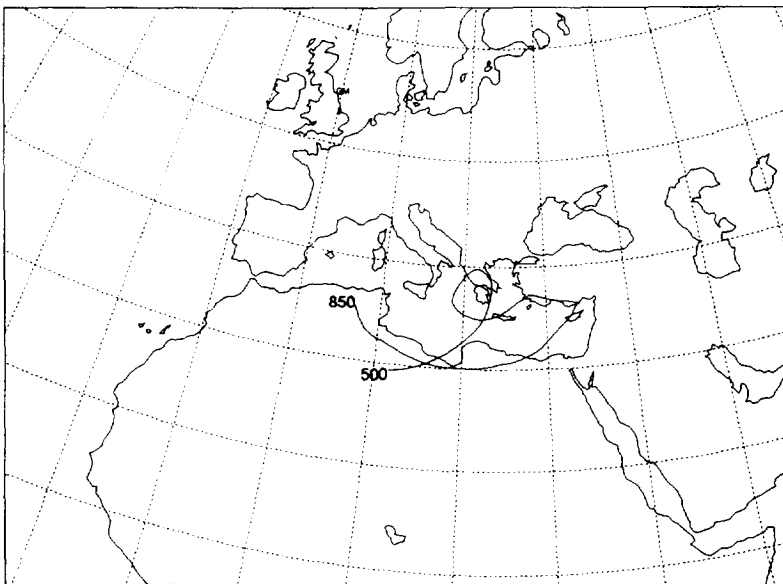
growing of the mixing height distribution on the sea to the times of late evening. Thereafter, the atmospheric dust in the upper layer has the possibility of downward mixing. Further, as can be seen from Fig. 5b, the lower layer trajectories were local that may permit the accumulation of both continental and marine origin elements in the atmosphere. Consequently, this characteristic atmospheric circulation

together with the deficit in precipitation during summer results in the accumulation of particles within the atmosphere.

During winter (December to February) cyclones predominantly traverse a route along the northern section of the Mediterranean (Alpert *et al.*, 1990) and, as can be seen from Fig. 3, local precipitations resulted in minimum geometric mean concentration

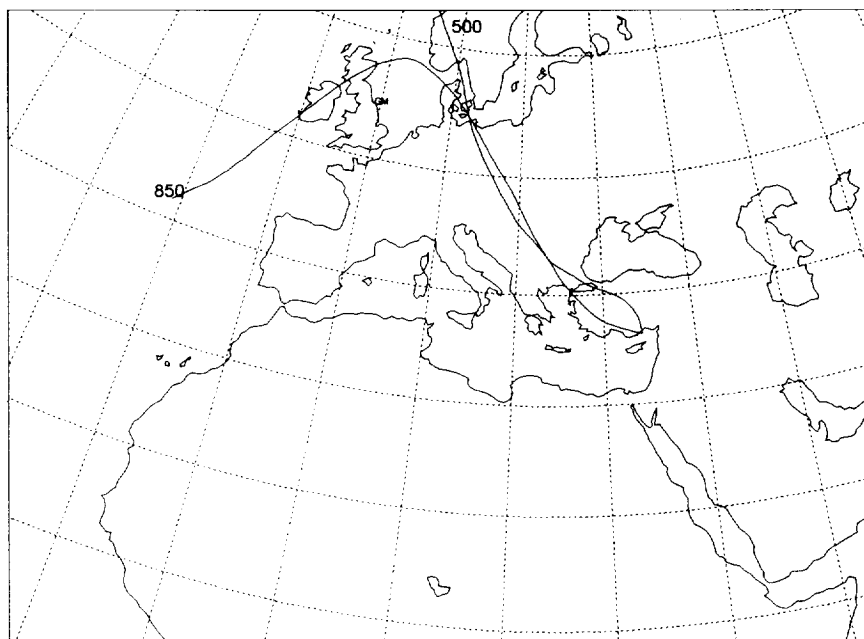


(a)



(b)

Fig. 4a and b.



(c)

Fig. 4. Air-mass backtrajectories arriving at 850 and 500 hPa levels: (a) 18 April 1992; (b) 21 April 1992; (c) 22 April 1992.

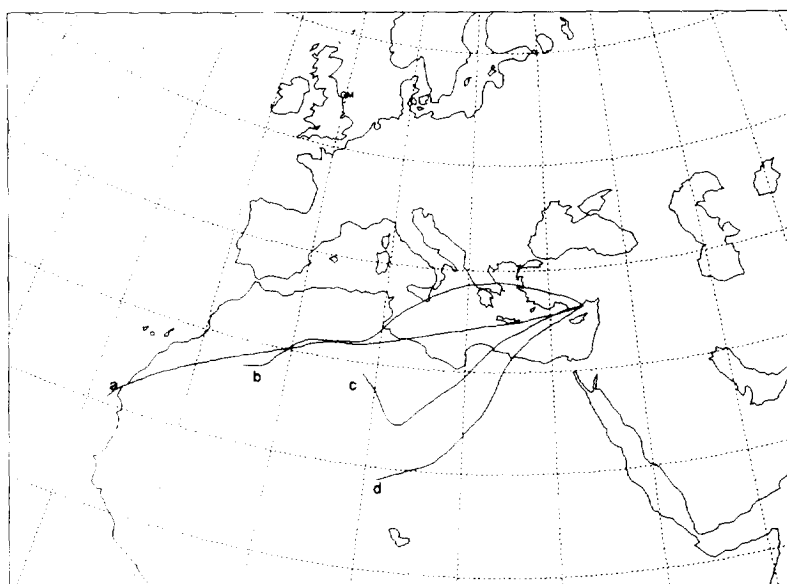
levels of Al and Fe that were 270 and 280  $\text{ng m}^{-3}$ , respectively. Thus, during winter the change in the wind regime together with precipitation scavenging strips out the atmosphere and it is only during this period that true "European background" concentration levels, as described by Chester *et al.* (1981, 1993), can be reached. These authors consider the aerosols over the Mediterranean Sea in terms of a system of two components, a European background (anthropogenic) and Saharan dust (crustal). The dilution ratio of the anthropogenic component by the crustal component differs on a seasonal and spatial basis throughout the basin. Figure 7 showing the three-dimensional air mass trajectories on 7 February 1992 illustrate the provenance of the air masses for the samples collected among 7 and 10 February. The mean elemental concentrations observed for this period for Al, Fe, Cd, and Zn were 680, 390, 0.10 and 14  $\text{ng m}^{-3}$ , respectively. During this period, the contribution of the crustal component in the atmospheric particulate must be minimal since local precipitation will have covered the soil with snow or wetness throughout the region traversed by the air masses on the Eurasia continent. The geometric mean of the elemental concentrations observed in winter was indeed at minimum levels (see Fig. 6).

Contrary to expectations, the concentrations of such anthropogenic elements as Cd and Zn, as illustrated in Fig. 6, reached their maximum geometric

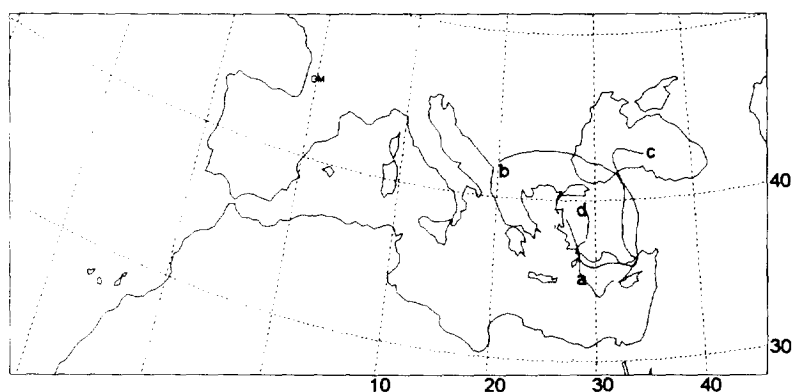
mean values of 0.21 and 34  $\text{ng m}^{-3}$  during the summer season. During winter these concentrations decreased to 0.19 and 13  $\text{ng m}^{-3}$ . Bergametti *et al.* (1989) observed similar behavior in the Western Mediterranean for the concentrations of the anthropogenic elements Pb and S and this unexpected trend was related to the local rate of precipitation. The beginning of the precipitation scavenging after the dry summer period in November coincides with the sharp drop in concentrations of Zn, Cd, Al and Fe (Figs 3a–d) in atmospheric particulate. The nadir of the elemental concentrations is reached towards the end of December when the elemental composition of particulate is governed by background levels. The pronounced seasonal variation in the geometric mean concentrations (Fig. 6) culminates in almost all elements (except Na and Cd) being at their minimum (background) concentrations in the winter months due to the combined effects of precipitation scavenging and airflow patterns. On the other hand, although rain scavengings persisted in spring and fall, the episodic and intense transport of dust from the surrounding deserts increases the mean concentrations of the elements.

The elemental analyses of the two size separated samples collected during 7–14 August and 26 October–6 November 1992 are illustrated in Figs 8a–d for the elements Al, Fe, Cd and Zn. As expected, irrespective of the sampling period, the high concentrations of Al and Fe dominated those fractions having





(a)



(b)

Fig. 5. Air-mass backtrajectories arriving at 500 hPa (a) and 850 hPa (b) for summertime: a 10-6-92; b 9-7-92; c 6-8-92; d 19-9-92.

diameters greater than  $10 \mu\text{m}$ . Figures 8c-d show that the size distributions of particles containing Cd and Zn exhibited a totally different behavior, confirming that the pairs (Al and Fe) and (Cd and Zn) possessed different types of sources. Further, the seasonal variation in concentration of the two pairs showed a marked difference. During August the contribution of small sized Zn and Cd containing particles was much more pronounced than in October–November. In other words, during summer over the Eastern Basin, there exist more small sized and aged atmospheric particles containing anthropogenic elements.

The transport of air masses through the atmospheric pathway from the Eurasian mainland between

December and February, together with local emissions, constructs the background concentrations of the elements specific to the Mediterranean basin. The intense activity of synoptic scale meteorological event enhances the uplift of crustal material over the desert region and transports these mineral aerosols as intense dust outbreaks in spring and autumn. This results in sporadic fluctuations of the concentrations of crustal and anthropogenic elements in the atmosphere during March–May and October–November, that can be defined as transitional periods. However, such an intense supply of crustal material along with the transport of anthropogenic elements from the European mainland results in a gradual increase in

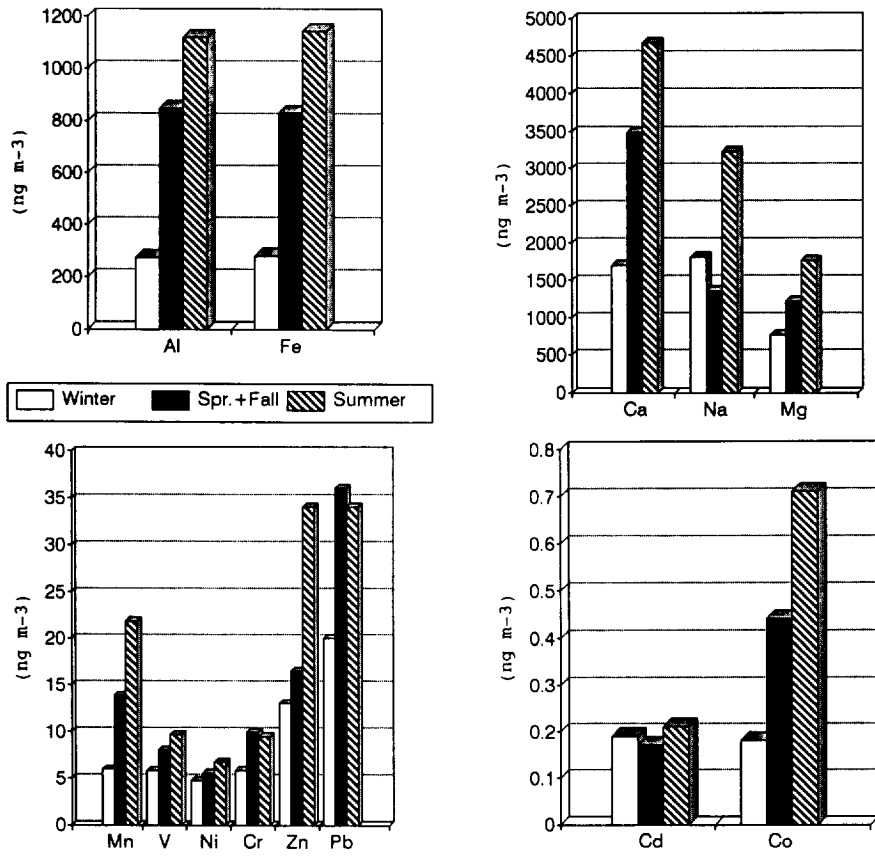


Fig. 6. Seasonal variation in geometric mean elemental concentrations over the Eastern Mediterranean.

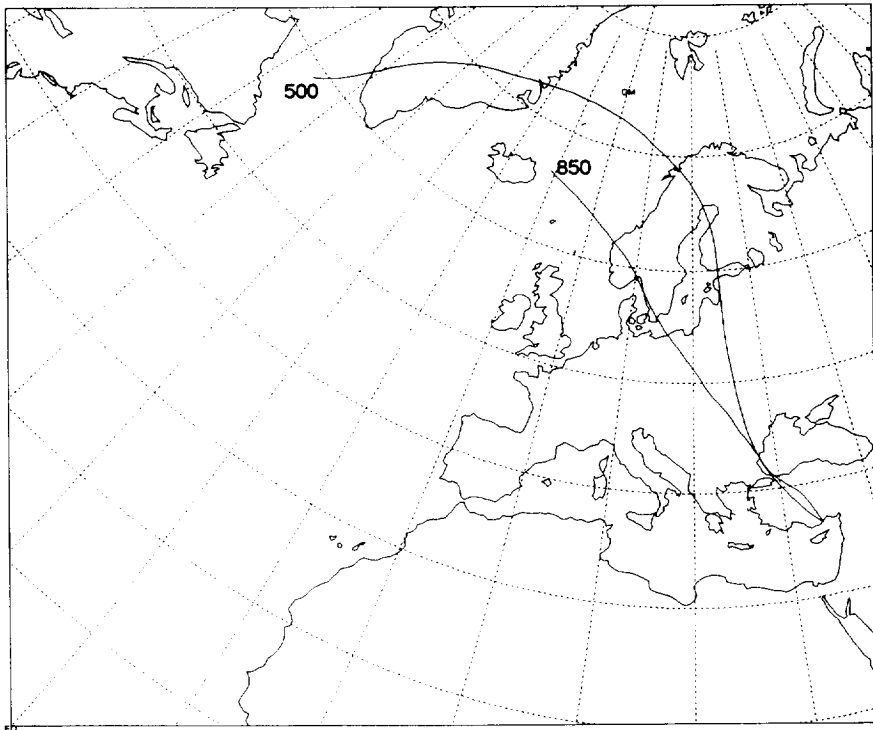


Fig. 7. Air-mass backtrajectories arriving at 850 and 500 hPa levels on 7 February 1992.

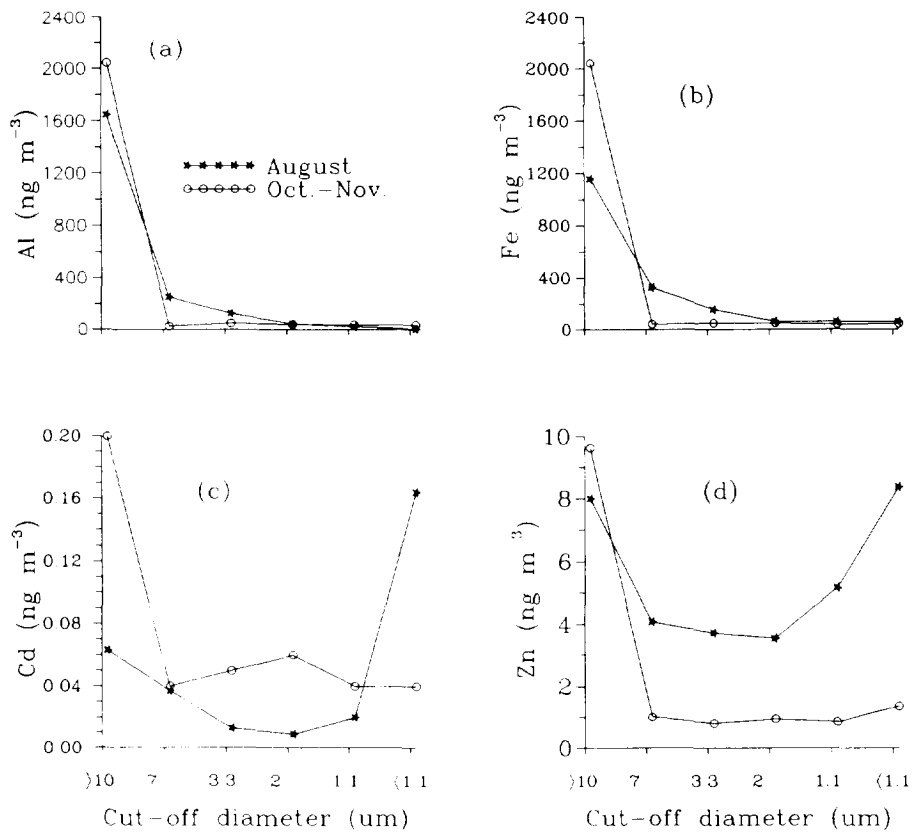


Fig. 8. Size fractionated atmospheric concentrations of the elements: (a) Al; (b) Fe; (c) Cd; (d) Zn.

the atmospheric load as wet scavenging gradually decreases towards summer. The formation of thermal stratification acts as a barrier between the upper atmospheric layer in which there is desert dust and the lower layer in which there are locally produced atmospheric particulates. The breakdown of the thermal stratification during diurnal cycles together with the effects of local sources increases the concentrations of elements in the atmospheric particulate during the dry summer months. Sporadic rains during this period can disturb the slow but steady build up of elements. The change in the transport of air masses which becomes apparent during autumn disturbs the nature of the accumulation of atmospheric particulate within the atmosphere of the entire basin. Intense rains at the beginning of the wet season strip out the atmospheric particulate matter and their associated elements. The observation of the high variability in the concentrations of elements throughout the entire basin during this period is due to the combined effects of crustal elements from their different source regions and the action of enhanced wet precipitation over the basin.

#### CONCLUSIONS

This first, long-term sampling of the atmosphere over the Eastern Mediterranean Basin and its com-

parison with the data previously obtained over the Western Basin has established the following.

- The annual variations in the concentrations of atmospheric particulate matter resemble each other over the entire Mediterranean basin.
- Air-mass trajectory analysis showed concentrations of the crustal elements (Al and Fe) to be an order of magnitude higher and of the anthropogenic elements (Cd and Zn) to be relatively lower when air masses came from North Africa rather than from the north.
- The Eastern Basin is dominated to a much greater extent by desert particulates than the Western Basin. The maximum concentrations of crustal material are entirely governed by the intensity of the air masses originating from the source regions.
- The composition of the atmospheric particulate matter corresponds to that of the true "European background" during the months December to February when the elemental composition of the atmospheric particulates reach their lowest levels throughout the entire basin.
- Two different sources (anthropogenic and crustal) of atmospheric particulates exist over the Eastern Mediterranean and this has been verified by the air mass trajectory analysis and the investigation of size separated samples.

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