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CONTRIBUTION OF SAHARAN DUST TO THE CENTRAL MEDITERRANEAN BASIN

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ABSTRACT

The Mediterranean Basin receives sedimentary contributions from several sources with different geological characteristics. The most important natural source of dust is the Saharan desert. Data from aerosol dust samples collected in a remote site in the Central Mediterranean Basin were used to investigate incursions of Saharan dust during a seven-month period (October-April). This paper is an attempt to trace source areas and transport of dust plumes by means of grain-size, mineralogical, and chemical analyses. Two sets of aerosol samples typical of "desert-influenced" and "anthropogenic-influenced" air masses were studied. We propose a model for assessment of the effects of latitude on the chemistry and mineralogy of the Central Mediterranean aerosol. Calculations and measurements of fluxes, in particular for Al (80 $\mu g/cm^2 \cdot yr^{-1}$) and Ca (28$\mu g/cm^2 \cdot yr^{-1}$), were performed, and results were compared with fluxes from the literature calculated in other stations in the Mediterranean Basin.

INTRODUCTION

Aeolian dust deposits are prominent in many parts of the world, in both continents and oceans (Pye, 1987), and play a major role in the formation of soils and deep-sea sediments. The continents are the primary sources of mineral aerosols, particularly in arid and semi-arid regions. Estimates of the amount of mineral aerosol generated in the particle-size range capable of long-range transport are in the order of hundreds to thousands of million tons annually (Peterson and Junge, 1971; Robinson and Robbins, 1968; Schütz, 1980). Fluxes of atmospheric solid particles across the air-sea interface can be of geological, pedological, and ecological importance. Aeolian dust can also affect the composition of ice in glaciers (De Angelis and Gaudichet, 1991; Waghenbach and Geis, 1989).

The Mediterranean Basin receives sedimentary material from a large number of sources with different geological characteristics. Saharan dust originating from North Africa is the major source of natural atmospheric particles over the North Atlantic and Mediterranean. The aeolian transport of desert aerosol is also responsible for the episodes of "red snow" or "red rain" described in various parts of Europe (Prodi & Fea, 1979; Bücher et al., 1983; Bergametti, 1987; Pye, 1987). In the following discussion, the generic term *Saharan* refers mainly to northwestern Africa (southern regions of Morocco, Algeria, Tunisia and Libya), which is considered to be the dominant dust source for the Central Mediterranean Basin. Whereas much time and study have been devoted to the transport of dust to the west (over the North Atlantic), very little is known about its transport to the north (over the Mediterranean). The transport of Saharan dusts over the Mediterranean region is poorly documented, although a few authors have studied one or two dust events from the meteorological, mineralogical or chemical points of view (Tomadin et al., 1984; Bücher et al., 1983; Ganor and Mamane, 1982; Chester et al., 1984; Lefèvre et al., 1986; Loye-Pilot et al., 1986; Dulac et al., 1987). Because these studies are limited in time, major questions

remain about the frequency of Saharan dust events in this region, and also about their source regions, transport processes and deposition patterns. The elemental chemistry of particulate material in the Mediterranean is essentially controlled by dilution of European background material (anthropogenic-influenced) with desert components (Chester et al., 1981). This diversity of sources is reflected in the composition of the aerosols; mineralogical markers can also be used to recognise typical *mineral assemblages* of the source areas, and to differentiate Saharan dusts from other crustal components (Tomadin and Lenaz, 1989). It would appear that latitudinal control exists over the distribution of mineral aerosols in the Mediterranean basin, with a general increase to the south (Guerzoni et al., 1989).

Furthermore, relatively little compositional data are available which may be used to characterize the desert-derived components and so identify actual incidents of the incursion of the dust over the central Mediterranean. In an attempt to investigate such incursions of Saharan dust, a series of aerosol collections were made in Sardinia.

In the present work, we would like to point out the differences between Saharan dust and other dusts from different sources, collected as a series of aerosols over a seven month period (October 1990 - April 1991). To reach this goal we used new and more complete way to analyze aerosol samples. Grain-size, mineralogical, and chemical parameters were employed for a better characterization of the aerosol. The two sets of aerosols for which data are reported here are representative of "desert-influenced" and "anthropogenic-influenced" air masses, and should offer ideal sample sets for evaluation of the effects of latitudinal controls on the chemistry of the Central Mediterranean aerosol. Moreover, our purpose was to investigate the amount and flux Saharan dust over the Mediterranean Sea, therefore some calculations and measurements of fluxes, and dry (aerosol dust deposited without rain) and wet (aerosol dust deposited during rain) deposition of trace metals to the Central Mediterranean, are presented and discussed.

Terminology

In this paper we use the terms according to the terminology in current use in the aerosol literature. The term "crustal-derived" or "crustal-dominated" or "crustal-components" is used to include samples .....The term "anthropogenic-influenced" or "anthropogenic-dominated" includes all samples influenced by pollutants and. The term "desert-influenced" or "desert-dominated" is used to include all the samples

METHODS

Sampling

Aerosol samples were collected at Capo Carbonara, a remote coastal station in southeastern Sardinia (Fig. 1), between October 1990 and April 1991. The sampling sites are 200 km north of the Sahara desert and more than 400 km from continental Italy (northeast) and France (northwest). The most abundant rocks in the station area are Paleozoic granitic plutons (Fig. 1). The principal winds are from the west and east-southeast, and the station is located far from local sources of pollutants. Sampling was carried out using a high-volume Sierra Andersen dry sampler, with filters made of 10 µm monofilament fibers located at upper level. Sampling lasted 24 to 72 hours.

In this preliminary study we have considered six samples: two with prevailing winds from the west; two with prevailing winds from the east-southeast; one with mixed wind directions; and one with prevailing winds from the northeast-east.

Analytical techniques

Aerosols were removed from the filters by washing in 'Milli-Q' DDW in the laboratory. Water-soluble particles were removed from the samples.
Particle size analyses of the insoluble particulate matter were carried out using a Model TA II Coulter Counter, linked to an automatic data acquisition system (Boldrin et al., 1986) for particle counting. Orifice tubings of 50 µm and 102 µm were used to

investigate the size domain after a preliminary scansion during which no larger grains were detected.

Mineralogical studies were performed by X-ray diffraction on powders and oriented-particle mounts. For convenient identification and systematic morphological analysis of the different minerals, a scanning electron microscope (SEM) fitted with an X-ray energy dispersive system (EDS) was used. Major elements were analysed on a flame AA spectrophotometer; trace elements were run using a graphite furnace. Analytical precision and procedures are presented in detail elsewhere (Guerzoni et al., 1987; 1991).

RESULTS AND DISCUSSION

Central Mediterranean southern trades (CMST) aerosol population

Cyclonic activity in the Mediterranean Basin is most intense during late winter and spring, when blocking anticyclones are frequently observed over the Atlantic. During these periods air masses commonly come from West Europe. Sometimes (~ 15% of yearly frequency) a deep Atlantic trough reaches North Africa and causes a strong flow from the south over the Mediterranean. Dust storms moving from the Sahara to the Mediterranean generally occur between October and May (Bücher 1989). Thus, meteorological conditions make concentrations of crustal material in the aerosols fluctuate. There is also evidence of the presence of dust "pulses" during the collection period.

The amounts of total suspended particles (TSP) and mineral suspended particles (MSP) are reported in Table 1, together with air-mass provenance and wind speed. Concentrations of TSP values range from 11.3 $\mu g/m^3$ for non-crustal components to more than 97.8 $\mu g/m^3$ for crustal ones. The average TSP content in non-crustal components is 24.6 $\mu g/m^3$, whereas during the southern wind episodes the average mass loading increases up to 88 $\mu g/m^3$. Accordingly, the MSP fraction is 0.8-3.3

$\mu g/m^3$ constituting 3-10 % of the total mass of dust for the former group, and 40-47.6 $\mu g/m^3$, i.e., 49-52% of the total mass of dust transported during southerly episodes. Therefore, four of the samples represent anthropogenic, maritime and local aerosols, and two, represent desert-dominated aerosols.

Both crust-dominated episodes were related to the position of the sub-tropical anticyclone over the Northeastern Atlantic and to the presence of polar air-masses over both the Atlantic Ocean and the continent. The first was recorded in October 1990 and the second in March 1991; the latter is presented in Fig. 2, which shows meteosat photographs and the synoptic meteorological situation at 500 mb.

Our values of TSP during Saharan events may be compared with TSP of 92 $\mu g/m^3$ (Lefevre et al., 1986) along the southern coast of Sicily influenced by Saharan sources during August 1984, back-air trajectories were predominantly westherly; concentrations of 72 $\mu g/m^3$ south of 40° Lat N on board ship during February 1983, back-air trajectories were predominantly southerly clearly indicates the unique contribution from North Africa (Correggiari, et al., 1989); concentrations of 100 $\mu g/m^3$ during October 1979, back-air trajectories were all predominantly southerly and indicate that the winds had crossed part of the North African mainland (Chester et al., 1984).

Our values of TSP during non-Saharan events may be compared with TSP of 33 $\mu g/m^3$ along the southern coast of Sicily during July 1984, back-air trajectories were predominantly northerly; concentrations of 5 $\mu g/m^3$ southern Tyrrhenian Sea on boerd ship during November 1982, back-air trajectories were predominantly northwesterly (Guerzoni et al., 1989); concentrations of 11 $\mu g/m^3$ during October 1979, back-air trajectories predominantly easterly.

Size distribution and mineralogical composition of aerosol

We have not found any previous studies reporting size analyses of aerosol samples collected at land stations. This is the first study to report the size distribution of Saharan dust from a land station.

The grain-size distribution of the investigated dust samples is between 0.63 and 102 µm, mainly falling between 0.63 and 4 µm.

Comparisons between representative cumulative curves of the samples are shown in Fig. 3. Particle size analysis mainly reveals the presence of silty clays or clayey silts. The cumulative curves indicate the median (Md), accurately shown at the 50 percentile.

The crustal-dominated samples, 3 and 42, have Md values of 4.5 and 2.1 µm, at wind speeds of 6 and 5 m/sec respectively from east-southeast; the non crustal-dominated samples usually have a lower Md values. Sample 22 has a Md value of 0.98 µm, at wind speeds of 9 from the west; sample 21 has a Md value of 1.0 µm, at a wind speed at 8 m/sec from several directions; sample 28 has a Md value of 1.4 µm, at a wind speed of 7 m/sec from northeast-east; and sample 9 has a Md value of 7.2 µm, at a wind speed of 12 m/sec from west. Sample 9 seems to be the coarsest dust, probably related to different transport velocities, but also it may be considered a true local-dominated dust. Sample 28 seems to be a coarse dust, thus it may be contain some local material. As indicated in Fig. 3, the size distribution of the two desert-dominated aerosol is shifted towards different population. Bimodal distribution, already reported by Prodi and Fea (1979) as a characteristic of mineral aerosols from the Sahara (D'Almeida and Scütz, 1983) was also observed in our samples. In the bimodal distribution the smaller-particle mode can be assumed as the well-mixed long-range transport (> 500 km) fraction of the mineral aerosol over the desert, whereas the large-particle mode represents proximal contributions (100 - 500 km) activated during the "Sirocco" wind (a typical wind transporting coarse desert-derived dust in the low atmosphere). Instead, the distribution size, of the two anthropogenic and maritime-dominated aerosols are shifted towards smaller particles, probably related to low tranport velocities . It also seems reasonable to attribute individual differences in the size distribution of the Saharan dust collected at Capo Carbonara to different transport times, which are in turn related to different transport velocities and the different lengths of airborne trajectories.

Mineralogical analysis shows the following mineral assemblage: quartz, (the most abundant non-clay mineral), calcite, feldspars, dolomite, talc, illite, kaolinite, chlorite, and palygorskite. Our main purpose was to identify local and Saharan indicators, taking into account both morphology and particle species. We looked for mineral associations of some species generally considered as indicators of Saharan origin. In the two observed samples, the mineralogical assemblage is similar to that of other well-known Saharan dusts (Coudé-Gaussen, 1981; Pye, 1987). As in those dusts, besides a substantial proportion of quartz grains, the Capo Carbonara dusts show feldspars, kaolinite, palygorskite, and abundant dolomite. The two events of African contributions are of concern and are studied by SEM and EDS analysis. Shape and surface features of the particles are related to the processes resulting from aeolation because liberation from the source and SEM/EDS analysis of particle mineralogy reveals their possible allogeny.

Some authors have found that most particles forming a desert-dust plume originate during the wind erosion process as products of mechanical breakage of particle crusts or "splashing" (Gillette, 1981). Both coarse and very fine silt were observed by SEM. The high frequency of small, chemically rounded particles and clay mineral clusters also points to in-situ erosion of already very small particles. The most probable source areas for small particles are silt and clay sediments from floodplains, and fine-grained aeolian sediments probably rejuvenated by fluvial erosion (Coudé-Gaussen, 1982).

The most characteristic mineral in Saharan dusts is palygorskite, which is a very common clay in the limestone plateaus of the northern Sahara. The occurrence in our crustal-influenced samples of rounded palygorskite is a very good indicator of aeolian transport (Fig. 4 a - b). The size of these palygorskite particles ranged between 4 and 40 µm. Such grains are wind-shaped from varied clayey substrata of the Sahara and transported beyond the desert margins (Coudé-Gaussen and Blanc, 1985). Another characteristic mineral found was dolomite, sometimes very well preserved (Fig. 4 c). Most of the quartz particles have a subrounded or rounded form, and vary

in size considerably (Fig. 4 e - f). Among the altered grain types, calcite and feldspar grains commonly occur (Fig. 4 h).

Mineralogical and morphological properties also characterize particles of non-Saharan origin. It appears from mineralogical observation that quartz, feldspars, and talc are the characteristic local inputs, because we did find some unusually coarse (~40 µm) angular quartz (Fig. 4 d) and some very well-preserved feldspars (Fig. 4 g) that obviously came from the local plutons.

Elemental chemistry of total aerosol

Geochemical analysis of the total aerosol samples was performed. The concentrations of selected indicator elements are given in Table 2. The contents of Si, Al, Ca, Mg, and K in the Saharan samples was 10 to 30 times higher than in the others; the largest increase was observed for Ca content, associated with enrichments in calcite and dolomite. Concentrations correlated very well those of dust-loadings, in tandem with major contributors of crustal elements to TSP. The Al values of the crustal dust samples were high (~3000 ng/m^3), whereas the lowest Al values (~25 ng/m^3) were observed in non-crustal samples. Particulate Al in the atmosphere was associated almost exclusively with aluminosilicates, and for this reason it is commonly employed as an indicator of the amount of crustal material in an aerosol population (Chester et al., 1981; 1984; 1986). Clearly, the high Al concentrations over the Capo Carbonara station are the result of the transport of crustal material to that region from Saharan sources. Our Al concentrations are within the same orders of magnitude of those found for the northeast tradewinds off West Africa (e.g., Chester et al., 1979).

Table 2 also shows variations in the Al/Si ratios for the six samples. This ratio changes with particle size. Thus, anthropogenic and maritime-influenced samples 21 and 22 (the finest sampled) have an Al/Si ratio significantly lower than that of desert-influenced samples 3 and 42 (Fig. 3). This indicates the occurrence of a component of fine Si particles which are not, for their major part, associated with Al. These results

indicate an important relation between geochemical and grain-size analyses as shown also in Coude-Gaussen et al., 1987 their Fig. 11 .

Concentrations of other elements (Zn, Pb, Cd, and Cr) in the aerosol also show considerable variations between the two groups of samples (desert-dominated and anthropogenic-dominated) and, in order to understand the compositional differences in terms of crustal and non-crustal elemental sources, enrichment factors (EF) were used. Table 3 shows the EF of the analysed elements, calculated employing Al as a crustal reference element and according to the equation: $EF_{crust} = (E/Al_{air})/ (E/Al_{crust})$, in which E/Al_{air} and E/Al_{crust} are the concentrations of an element E and of Al in the atmosphere and in the crustal material respectively (e.g., Taylor, 1964). Enrichment factors close to one are taken to indicate that an element has a mainly crustal origin, and those greater than about 10 are considered to indicate that a substantial portion of the abundance of an element has a non-crustal source.

In the following sections, the possible origin of some of the elements is discussed and an attempt is made to distinguish the natural from the anthropogenic signature. In terms of EF, the Mediterranean Basin aerosols can be divided into three general groups: (1) non-enriched elements, with EF generally less than 10, i.e., Si, Ca, K, Mg, and Cr; (2) intermediate elements, with EF between 10 and 100, i.e., Cr, Ni, V, Cu, and (3) enriched elements, with EF which may exceed 100, i.e., Zn, Cd, Pb (Chester et al.,1984). Table 3 shows that enriched and non-enriched elements behave differently in the two sets of samples. Non-enriched elements generally have low ranges of EF in all samples. In contrast, there are considerable variations in the EF of enriched elements (Zn, Cd, and specially Pb). However, the EF for these elements are considerably higher in the non-Saharan samples. So high values cannot be considered of crustal origin, we never found any mineralogical evidence to support this hipotesis. Thus, a clear distinction can be made between the two sets of samples. This result is in agreement with most previous work on the Mediterranean Sea (Dulac et al., 1987; Bergametti, 1988; Chester et al., 1984; Correggiari et al., 1989) and shows that aerosol composition is influenced by both pollutants and crustal sources.

For comparative purposes, mean concentrations and EF crust data of trace metals in crust-dominated aerosols of various areas are listed in Table 4. CMST data are compared with an aerosol collected off the west coast of Africa (ANET) and with the Arabian Sea (AS) aerosol, collected during the northeast monsoon. These samples are among the most crust-dominated populations found in the World Ocean (Chester, 1986). Table 5 shows mean concentrations and EFcrust data of trace metals in anthropogenic-dominated aerosols of different marine areas, compared with the Sardinian samples.

Total atmospheric particle and trace metal fluxes

A considerable amount of data have been reported on mineral dust and trace metal fluxes over Atlantic (Buat-Menard and Chesslet, 1979) and on the qualitative aeolian contribution in the Mediterranean (e.g.,Chester et al., 1984; Tomadin et al., 1984) . However, few such flux data are available for CMS and from sampling sites close to the Saharan source.

Aerosol deposition from the atmosphere is controlled by a combination of wet and dry processes. Dry-deposition velocities of trace metals from the atmosphere vary with particle size (Arimoto and Duce, 1986). Acccording to data reported for the deposition of trace metals to the surface of the North Sea and Western Mediterranean (Dulac et al., 1987), dry-deposition velocities for crustal elements (Al, Fe, Si) are about 1.5 cm/sec and, because of nearness to the land, an average value of 1.5 cm/sec was assumed for these elements in CMST aerosols. In contrast, depositional velocities for anthropogenic elements (e.g., Pb, Zn and Cd), which are found on small particles, are reported to be less than 0.5 cm/sec.

Very few data on the wet/dry deposition ratio of trace metals over the Mediterranean are available (Gueiu et al., 1991; Guerzoni et al., 1991). We therefore integrated those data into the model proposed by Duce et al. (1976), in which it was assumed that wet deposition is approximately three times that of dry deposition, so that the total metal flux is four times the dry deposition flux.

The average trace metal concentrations of TSP, Ca and Al of all samples collected in seven months were used to calculate the dry and wet+dry deposition fluxes to the sea surface over the CMS as outlined above, and the total atmospheric deposition was weighted to take into account 10 months of dry deposition and only two months of wet+dry deposition. The frequency of crust-dominated versus anthropogenic/ maritime-dominated episodes was also considered in calculations. The yearly fluxes are 800 $\mu g/cm^2$ for mineral particles, ~80 $\mu g/cm^2$ for Al and ~30 $\mu g/cm^2$ for Ca. Contributions to sediments in the Central Mediterranean are therefore less than 1 mg/cm^2 year, i.e., 1 cm of sediment every 1000 years.

Figure 5 elucidates flux comparisons and indicates the effects of latitude on the MSP content of the Mediterranean aerosol. MSP aerosol values collected during southern events onboard-ship by our Institute in the period 1981-1983 (Correggiani et al., 1989) were plotted versus latitude, with other samples collected in the Central Tyrrhenian Sea by Chester and coworkers (Chester et al., 1984). In the same figure are also plotted dust loadings of samples (averages with ranges) collected from land-based stations with southern winds, at two different latitudes: Messina, Sicily (38°.1 Lat N, six years of weekly sampling by the Italian Meteorological Service; Cruciani et al., 1991) and Corsica (42°.3 Lat N, two years of daily sampling; Bergametti et al., 1988), together with our Sardinian station (39°.1 Lat N).

The very clear and constant latitudinal trend of dust loading in the Mediterranean atmosphere is striking, in spite of different periods and sometimes different collection techniques. The decrease in MSP concentration is exponential northwards, and the very good correlation coefficient ($r=-.76$, $p<0.001\%$) of the logarithm of MSP with latitude indicates halving of values approximately every 200 km.

Figure 5 also indicates the fluxes calculated in Sardinia and those derived from records in Alpine ice cores (45°.6 Lat N, Waghenbach and Geis,1989; De Angelis and Gaudichet, 1991), together with the amount of dust that travels every year northwards from the Sahara ($100x10^6$ tons). The curve may explain the variations comparison between the two sites in terms of fluxes: the distance from Sardinia to the Alps is

approximately 800 Km (4x200 Km) and differences in fluxes are 10-20 times (i.e., 2^4, equivalent to four halvings).

SUMMARY AND CONCLUSION

(1) Combined analysis of the grain-size, mineralogical, and chemical properties of aerosol dust is a good way to discriminate between "desert-influenced" and "anthropogenic-influenced" air masses.

(2) The volume size distribution of desert-influenced aerosols is shifted towards larger particles and a bimodal distribution was observed. Instead, the volume size distribution of anthropogenic-influenced air masses is shifted towards smaller particles.

(3) Palygorskite, dolomite, calcite, and rounded quartz are strongly suggestive of desert-influenced air masses.

(4) Si, Al, Ca, Mg, and K concentrations in desert-influenced samples are about 10 to 30 times higher than in anthropogenic-influenced samples.

(5) The Al/Si ratio is a good discriminator between desert- and anthropogenic-influenced samples, with high values in the former group and low ones in the latter.

(6) Enrichment factors (EF) for enriched elements (Zn, Cd, and especially Pb) do not exceed 100 in desert-influenced samples. Instead, they exceed 100 many times in anthropogenic-influenced samples.

(7) An exponential curve for aerosol mineral loading was calculated between 35° and 45° Lat N, and the northward decrease of MSP values fits most of the published data.

(8) The same curve may also explain variations between particle fluxes calculated at Capo Carbonara (less than 1 mg/cm^2 year) and those recorded in ice cores in the Alps.

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TABLE CAPTIONS

Table 1. Sample number, air-masses origin, wind speeds, total suspended particles (TSP), mineral suspended particles (MSP) and insoluble fraction collected at Capo Carbonara.

Table 2. Chemical composition and Al/Si ratio of samples collected at Capo Carbonara.

Table 3. Enrichment factors (EF) of the study samples.

Table 4. Mean concentration (ng/m^3) and EF values of trace metals in desert-dominated aerosol.

CM: Central Mediterranean/ present study

ANET: Atlantic northeast trade/ Murphy, 1985

AS: Arabian Sea/ Chester et al., 1991.

Table 5. Mean concentration (ng/m^3) and EF values of trace metals in anthropogenic-dominated aerosols.

SARDINIA: present study

CORSICA: Bergametti et al., 1988

N. SEA: Cambray et al., 1975.

FIGURE CAPTIONS

Fig. 1. Geographical map of Mediterranean Sea, and location of sampling station with geological sketch. (1) colluvial, alluvial, fluviolacustrine and fluvioglacial deposits, Pleistocene ; (5) alkaline and subalkaline basalts, trachybasalts, basanites, tephrites and sodic trachyandesites, andesitic basalts, Neogene; (7) rhyodacites, rhyolites and liparites, Miocene; (10) granites and granodiorites, Paleozoic; (11) tonalites including smaller masses of diorites, Paleozoic; (13) gabbros, Paleozoic; (14) rhyodacites and rhyolites (ignimbrites), Permo-Carboniferous; (24) marls, commonly with chert, of pelagic facies, Middle-Lower Miocene; (81) marine deposits, mainly arenaceous units, Silurian-Ordovician; (82) marine deposits, mainly shaly units, sometimes carbonaceous, Silurian-Ordovician.

Fig. 2. IR Meteosat photo (top) and synoptic meteorological situation at 500 mb (bottom) of southern transport episode of March 1991.

Fig. 3. Cumulative grain-size curves of six dust samples collected at Capo Carbonara. Solid line: Saharan samples; broken line: non-Saharan curves.

Fig. 4. Scanning electron micrographs of tracer minerals: (a) wind-shaped palygorskite grain; (b) close-up of (a) showing palygorskite fibers, sample 42; (c) very well-preserved dolomite crystal, sample 42 ; (d) huge angular quartz (~40µm), sample 22; (e) very small smooth quartz of desert type, sample 3; (f) large wind-shaped quartz grain, sample 42; (g) very well preserved angular feldspar grain, sample 28; (h) rounded and altered feldspar grain, sample 3.

Fig. 5. MSP values of aerosol dusts plotted against latitude. Open squares are samples collected onboard-ship by Institute in period 1981-1983 (Correggiari et al., 1989); filled squares: samples collected onboard-ship in Central Tyrrhenian Sea by Chester and coworkers (Chester et al., 1984).

Filled symbols indicate average values (with ranges) from land-based station on islands: triangle: Messina, Sicily, 5 years weekly sampling (Cruciani et al., 1991); asterisk: Capo Carbonara, Sardinia, present work; circle: Capo Cavallo, Corsica 18 months daily sampling (Bergametti et al., 1988). Lower part of plot: sketch profile from Africa towards Europe along 9° Long E. Left: Africa, showing amount of dust that leaves Africa northwards (D'Almeida 1986).
Centre: Capo Carbonara, fluxes calculated in this study.
Right: Alps, average fluxes (40 years) recorded in ice cores (Waghenbach and Geis, 1989; De Angelis and Gaudichet, 1991.)