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SOME AEOLIAN FEATURES IN THE PO PLAIN NEAR ESTE (NORTH ITALY)

ABSTRACT: RIZZETTO F., MYCIELSKA-DOWGIALLO E. & CASTIGLIONI G.B., *Some aeolian features in the Po plain near Este (North Italy).* (IT ISSN 0391-9838, 1998).

In the cultivated Venetian plain, aerial photographs show evidence of scattered distributions of whitish speckles, interpreted as residues of small sand bodies alternating with fine alluvial sediments. Similar patterns occur SW of the Euganean Hills, where ancient fluvial sandy ridges, the remains of Holocene and Pleistocene abandoned courses of the Adige river, are also evident.

In this paper, one special group of presumed aeolian forms is described in the neighbourhood of Este (province of Padova). Studies of aerial photographs (which give evidence of small scattered residues of dune fields) are first presented; then a single preserved relief, interpreted as a dune, and an elongated depression, tentatively interpreted as a deflation hole, are briefly described; lastly, the results of sedimentological analyses on both dune sands and fluvial sediments are presented.

In the conclusive discussion, the authors observe that all these elements give good support to the interpretation of the relief as a true aeolian accumulation form and indicate the presence of other deposits of fluvio-aeolian origin.

KEY WORDS: Aeolian forms, Alluvial plain, Aerial photograph interpretation, Granulometric analysis, Heavy mineral analysis, Po Plain.

RIASSUNTO: RIZZETTO F., MYCIELSKA-DOWGIALLO E. & CASTIGLIONI G.B., *Alcuni fenomeni eolici nella Pianura Padana vicino ad Este (Italia settentrionale).* (IT ISSN 0391-9838, 1998).

Nella pianura padano-veneta le fotografie aeree permettono di distinguere sul terreno agrario insiemi di «macchie» con toni più chiari rispetto alle aree circostanti, interpretate come residui di piccoli corpi sabbiosi alternati a sedimenti alluvionali più fini. Più in particolare, simili *patterns* si rinvengono anche a SW dei Colli Euganei, dove sono pure evidenti antichi dossi fluviali sabbiosi legati a paleocorsi pleistocenici ed olocenici del Fiume Adige.

In questo lavoro vengono descritte alcune probabili forme eoliche rinvenute nei pressi di Este; inizialmente si parla delle indagini compiute sulle fotografie aeree (che hanno permesso di individuare i corpi sabbiosi); segue la descrizione di un singolo rilievo, tuttora preservato, associato ad una depressione allungata (ritenuti essere rispettivamente una duna eolica ed una conca di deflazione); infine vengono esposti i risultati delle analisi granulometriche e mineralogiche condotte sui sedimenti raccolti.

Nella discussione conclusiva gli autori affermano che tutti questi elementi concordano nel far interpretare il suddetto rilievo come una vera duna prodotta dal vento ed inoltre confermano la presenza di depositi fluvio-eolici in località Dossi.

PAROLE CHIAVE: Forme eoliche, Pianura alluvionale, Fotointerpretazione, Analisi granulometrica, Analisi dei minerali pesanti, Pianura Padana.

INTRODUCTION

Italian geomorphologists have generally paid more attention to loess covers than to sandy aeolian deposits in the inner part of the Po plain. In the southern part of the Veneto plain, aeolian forms associated with the dominant fluvial morphology were sometimes mentioned by previous authors (Nicolis, 1898), but no real research was later carried out on this subject. In other sections of the Po plain, continental dunes, although not frequent, are often mentioned. In the western part, a few dunes have long been known near Turin and have recently been mapped in the *Carta Geomorfologica della Pianura Padana* (1997); other published data refer to several old dunes in the plain near Pavia (Boni, 1945; Gabert, 1962), but their existence is not

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This research was carried out within the cooperation agreement between the Universities of Padova and Warsaw. Dr. F. Rizzetto studied many examples of small aeolian features in the low Venetian plain from aerial photographs and carried out granulometric analyses on sands; Prof. E. Mycielska-Dowgiallo directed sedimentological studies and interpretations; Prof. G.B. Castiglioni wrote the introduction and the short description of the area near Este.

Funds for this research were provided by the Italian Murst, National project «Catene Montuose e Pianure, Geomorfologia Strutturale ed Evoluzione in Italia e in Aree Mediterranee», Resp. Prof. P.R. Federici (Pisa); publication co-funded by Murst 1996 and 1997, National projet «La risposta dei processi geomorfologici alle variazioni ambientali».

Dr. P. Zangheri (Padova) took part at the beginning of this research. Heavy mineral analyses were carried out by Dr. A. Barczuk, University of Warsaw. Dr. A. Bondesan (University of Padova) helped in the use of the stereo facet plotter. Dr. F. Rizzetto carried out granulometric analyses: some were done at the Department of Geological and Paleontological Sciences of the University of Ferrara (Italy), with the help of Prof. M. Bondesan, Dr. U. Simeoni and Mr. G. Calderoni.

confirmed by later geomorphologists. Within the moraine amphitheatre of Rivoli Veronese, Habbe (1969) described sand dunes in the late-Würmian fluvioglacial domain of the Adige glacier. In the southern Friuli plain, continental dunes were surveyed near Aquileia (Comel, 1951; Cavallin & *alii*, 1987). The frequent destruction of such features due to human activity, especially sand quarrying and land reclamation, must be pointed out.

This paper presents a case study, concerning in particular aeolian forms near Este. This area is part of the old alluvial plain of the Adige river (fig. 1), whose sediments are characterized by the presence of reddish potassium feldspar, yellow-brownish flakes of biotite, and brownish or reddish grains originating from the decay of porphyry (Jobstraibizer & Malesani, 1973).

Aeolian accumulation forms of various ages are common features along the coastal belts of Italy and are often reported in the geomorphological and geological literature. In the present paper, a second case study, regarding features in the ancient coastal belt of the Veneto plain, is briefly described for the sake of comparison.

SMALL FEATURES OBSERVED FROM AERIAL PHOTOGRAPHS

Preliminary research was carried out by Rizzetto (1993-94) on various kinds of aeolian landscapes, in both present-day and old littoral sand barriers. As an example, fig. 2 shows features observed in old sandy ridges South of the Adige river, 12 km inland from the Adriatic. They belong to the oldest Holocene dune alignment identified in the coastal belt South of the Lagoon of Venice (Favero & Serandrei Barbero, 1979)

The NNE-SSW direction of the dune chains (fig. 2) corresponds to the ancient coastlines, and the shape of the single speckles demonstrates aeolian reworking of sandy sediments. The NE wind called «*bora*» is the most efficacious in the area. Agricultural activity has not greatly influenced the apparent shape of these speckles, although it has reduced the altitude of the convex forms. The size of the sand speckles ranges from about 50 to more than 100 metres in diameter.

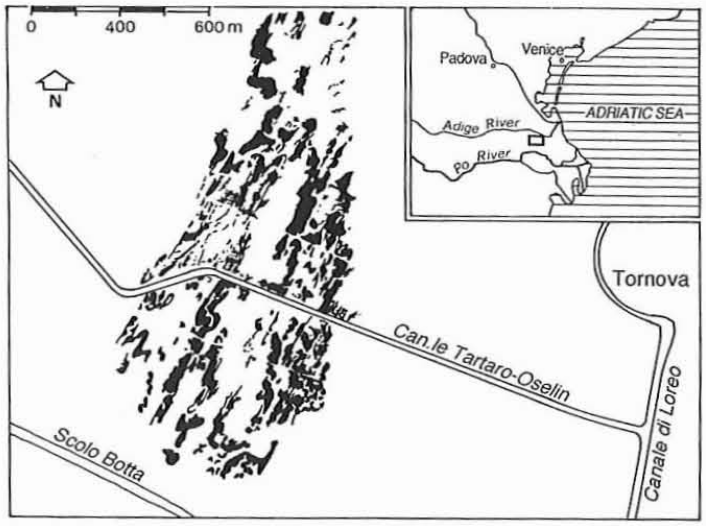


FIG. 2 - Irregular pattern of small sand dunes in proto-historical coastal belt South of present Adige river (from aerial photographs published by Tozzi, 1987).

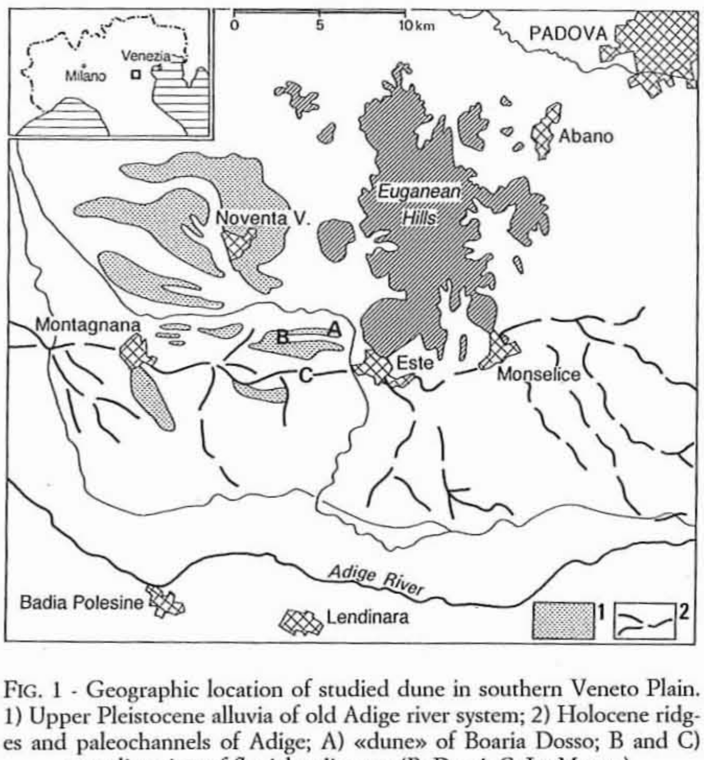


FIG. 1 - Geographic location of studied dune in southern Veneto Plain. 1) Upper Pleistocene alluvia of old Adige river system; 2) Holocene ridges and paleochannels of Adige; A) «dune» of Boaria Dosso; B and C) sampling sites of fluvial sediments (B: Dossi; C: La Manna).

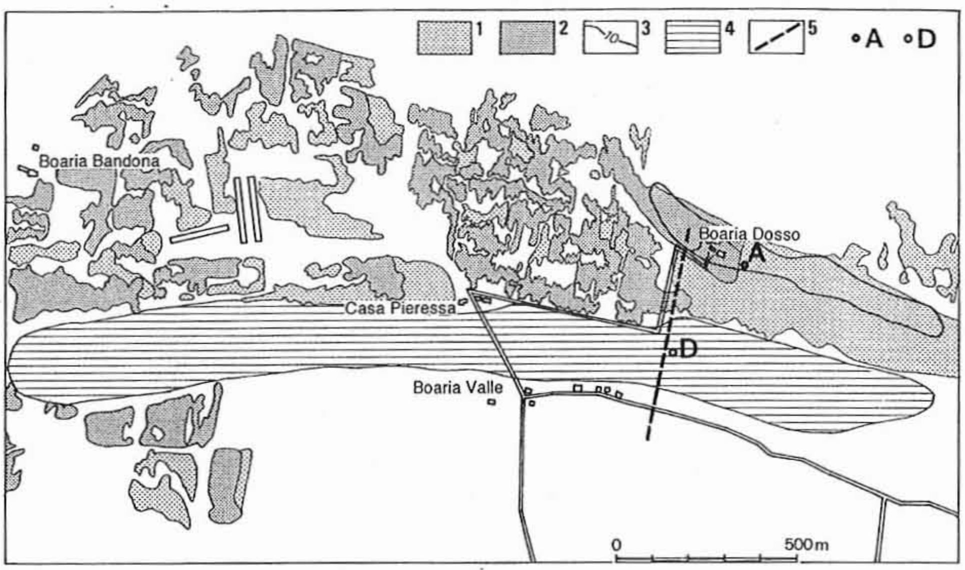
AREA NORTH-WEST OF ESTE

General description

The alluvial plain SW of the Euganean Hills (fig. 1) was mainly built up by aggradational processes connected with the Adige river system. During both late Pleistocene and Holocene, this aggradation hindered some smaller rivers coming from the North (Zangheri, 1990). The activity of the main river along the Montagnana-Este-Monselice alignment and its lateral branches ended in the 6th century A.D. (Zaffanella, 1981; Marcolongo & Zaffanella, 1987) when the Adige finally changed its course towards Badia Polesine, through which it now flows. Well-preserved fluvial sandy ridges are characteristic of pre-Roman and Roman courses between Montagnana and Este, as well as noteworthy remains of older elongated sandy-silty bodies, some of which support soil more than 1 m thick: the latter are approximately mapped as Upper Pleistocene alluvia in fig. 1.

NW of Este, detailed fluvial ridge-and-basin topography shows some special features supporting the hypothesis of aeolian reworking. Zangheri (1987-88) found evidence of aeolian sediments by means of granulometric analysis of sand samples; contours interpolated using altitude data (al-

FIG. 3 - Distribution of whitish speckles near Boaria Dosso, in relation to local geomorphology. 1) areas with middle-low density of white speckles on aerial photographs (1982 and 1990); 2) areas with high density of white speckles on aerial photographs (1982 and 1990); 3) dune, represented by 10-m contour; 4) depression, with clayey sediments rich in organic material; 5) trace of cross-section presented in fig. 6; A) site of hand-boring and sampling; D) site of 14-C dated peat sample (from Zangheri, 1987-88).



though topographical maps are not completely satisfactory from the viewpoint of altimetric information) and direct observation provide evidence of one relief more like an aeolian feature than a pure fluvial sedimentary form. As shown in fig. 3, the Boaria Dosso farm is located on an elongated hill stretching WNW-ESE. The mean altitude of the surrounding plain runs at 8-9 m a.s.l., while the top of the hill reaches 12.35 m a.s.l.. Along its southern flank, there is a long depression filled with dark-grey clayey sediments, whose present-day bottom drops to a minimum altitude of 7.3 m a.s.l..

In this area, research was carried out by means of: (i) aerial photograph interpretation; (ii) analyses of sediments collected with hand-boring equipment; (iii) age determinations on other samples.

Evidence from aerial photographs

At the beginning of research, detailed analysis of the area was carried out on both existing maps and aerial photographs taken in 1982 and 1990. These photographs reveal many speckles on the agricultural land (characterized by a lighter colour than the surrounding areas), which are of great interest because they give evidence of local sand deposits.

As in the older photographs (taken in 1982) these speckles appear more distinct, with well-defined outlines, it was considered appropriate to analyse them in three different ways:

1) «by sight» (without using special instruments) to estimate the general distribution and morphology of the paler speckles (fig. 4);

2) using a stereoscope, which gave evidence of the convex relief of Boaria Dosso, interpreted as a dune;

3) using a stereo facet plotter: besides providing a stereoscopic view of photographs, this instrument also allows observation of maps and photographs at the same time, the latter superimposed on the former. Elements from the photographs may thus be transferred to the map with great precision.

Similar distribution of the light speckles appears when the two series of photographs, taken eight years apart, are

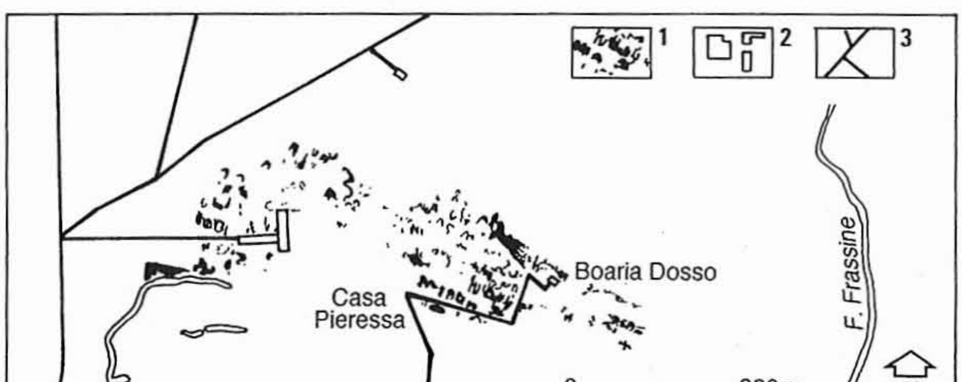


FIG. 4 - Details of aeolian morphology as revealed by aerial photographs taken in 1982 near Boaria Dosso.

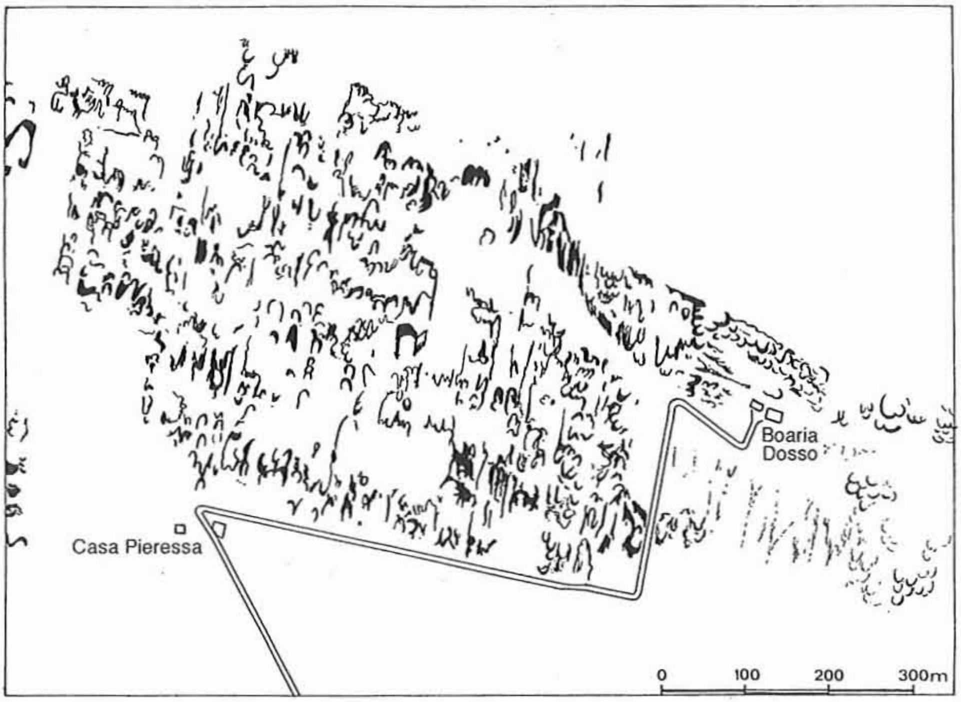


FIG. 5 - Details of aeolian morphology obtained by analysing photographs, taken in 1982, using a stereo facet plotter.

compared. This means that they are not due to human working of the land in the last few years, but to an older natural phenomenon. In particular, the speckles are irregularly distributed between Boaria Bandona and Boaria Dosso. Fig. 4 shows their general distribution: some are like sinuous chains running more or less E-W, while others are half-moon shaped with generally N-S or NNE-SSW axes. A section of the area in fig. 5 represents an example of analysis obtained using the stereo facet plotter. Enlarged and stereoscopic views of the same photographs clearly identify all the speckles and also a longer relief like a dune. Smaller spots form dense sets of speckles which are often half-moon shaped; this pattern is occasionally disturbed by human activity.

Fig. 3 shows the main pattern of distribution of the whitish speckles which are present in both series of photographs, as probable aeolian features. There are two types of distribution: (i) areas characterized by dense whitish speckles; (ii) areas with middle-low speckle density. There are also some areas which cannot be analysed due to vegetation cover.

In the western part of the area, the speckles are larger than in the nearby areas. They have irregular contours and are generally due to the aggregation of small crescent-shaped speckles; their density of distribution varies between 20 and 30% of the total surface area.

In the central part, small speckles are closely arranged, sometimes joining up to create sinuous chains. These are generally crescent-shaped like the others, although their shape is sometimes indistinct due to agricultural working of the land. Density is 30-40%.

The eastern part contains large faint spots, with indefinite contours. Lighter parabolic speckles may be observed on the relief of Boaria Dosso, with main WNW-ESE axes.

On the whole, the shape and orientation of the speckles, interpreted here as probable aeolian features, fit a prevalently NNE-SSW wind direction. Some of the speckles resemble simple barchans or transverse barchanoid ridges. However, combination with other winds responsible for the main forms running WNW-ESE or W-E is also possible.

The hill of Boaria Dosso and sediment sampling in the area

Although this hill has been reshaped by agricultural working, it is a prominent feature of the landscape, is evident in detail, and has not changed its general morphological aspect. In the surrounding plain, depressions and ridges run parallel in an approximately E-W direction. Attention must be paid to the long depression South of Boaria Dosso (fig. 3): it is about 300 m wide and is bordered to the South by a long gentle ridge composed of alternating fine sandy-silty layers. The cross-section (fig. 6) indicates the original form of the bottom of the depression, composed of sand, before it was filled with clayey sediments. The radiocarbon age determination on a sample of peat, collected from a depth of 1.5 m by Zangheri, turned out to be 3,745 ± 85 y. B.P. (GX-14469). This fits the hypothesis that the Adige river did not play a part in shaping this depression in historical times and that the bordering sandy ridges are also old features.

Sand samples for sedimentological studies were collected from the following points (see table 1 and fig. 1):

A - on the top of the hill near Boaria Dosso;
B - at Dossi, on a ridge situated 5 km to the West;

TABLE 1 - Sample numbers and depths

Sample number	Depth (cm)
1	70-75
2	100-105
3	127-132
4	163-168
5	195-200
6	228-232
7	264-269
8	295-300
9	327-332
10	350
11	375-380
12	400

A. Old «dune» (Boaria Dosso)

Sample number	Depth (cm)
1	150- 160
2	200-205
3	215-220
4	255-270

B. Old fluvial ridge (Dossi)

Sample number	Depth (cm)
1	105-110
2	190-195
3	300-310

C. Recent fluvial ridge (La Manna)

C - at La Manna, on the fluvial ridge running South between Montagnana and Este, where the Adige flowed during proto-historical and historical times.

A sample of fine sand was also collected from a depth of 1.5 m not far from Dossi. Its TL age determination was 109,000 ± 16,000 y. B.P. (Wa 21-90). This considerable age also fits the hypothesis that the main forms NW of Este belong to the relict surfaces of the Upper Pleistocene plain (fig. 1). In fact, where preserved, a soil layer 1.0-1.5 m thick may be identified on the surface of the «old» sandy fluvial ridges and of the hill of Boaria Dosso.

SEDIMENTOLOGICAL ANALYSES

Granulometric analysis of samples was performed using a combined sieve and aerometric method. Samples were sieved at half-phi intervals. Results provided frequency and cumulative curves (with grain diameter plotted on the abscissa and weight per cent on the ordinate on the log-probability scale). The percentages obtained from this second kind of diagram were then used to calculate the most significant statistical parameters: graphic mean grain diameter D_m, inclusive graphic skewness Sk_1, inclusive graphic standard deviation σ_1 (Bosellini & *alii*, 1989) and sorting coefficient $\sigma_\varnothing$ (Ricci Lucchi, 1973).

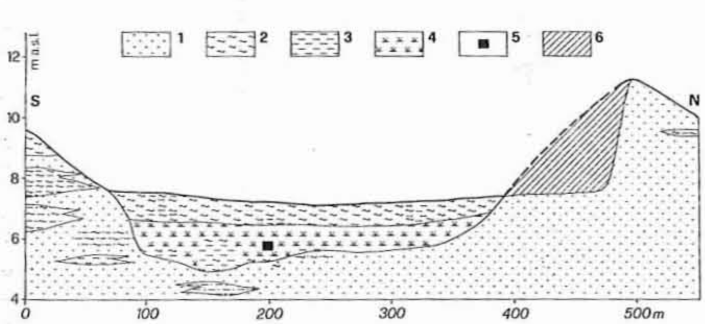


FIG. 6 - Cross-section of depression South of Boaria Dosso (from Zangheri, 1987-88, modified). 1) sand; 2) silt; 3) clay rich in organic material; 4) peat; 5) dated level; 6) probable lack of sediments due to human activity.

Lastly it was important to analyse heavy minerals and to take into account their vertical distribution at various depths. All these results provided information on the origin of the investigated deposits and the dynamics of the processes which gave rise to them.

Results of granulometric and heavy mineral analyses

A - Old «dune» (Boaria Dosso)

The twelve samples collected at Boaria Dosso are medium - fine sands and are quite well sorted; all their frequency curves (fig. 7) are unimodal and highly peaked. In particular, the first three have their peaks in the 1.5-2.0 Ø fraction, the others in the 2.0-2.5 Ø fraction.

Comparison of these curves shows a general decrease in grain size from sample 1, which is the coarsest and represents the top deposit, to sample 8. Although the opposite trend (an increase in grain size) appears twice from samples 8 to 9 and from 11 to 12, low variability in granulometric composition characterizes the deepest sediments because, with the exception of sample 11, they all have very similar frequency curves.

Other sediments with the same granulometric distribution are samples 6 and 7. Samples 4 and 5 overlap perfectly on the left side of the diagram.

Very interesting information on environmental dynamics may be obtained from the cumulative curves on the log-probability scale. They are composed of straight lines which highlight three main different kinds of sediment transport: suspension, saltation, and surface dragging and rolling (Visher,1969).

All these curves have similar characteristics (see fig. 7): each sample is composed of a large saltation population of grains and a low percentage of material transported by suspension; sands resulting from bottom traction do not appear in all samples and, when present, they occur in very small quantities. Some curves partially overlap: for example, samples 6, 7 and 9 are similar, but the grain size of the suspension material increases from samples 6 to 9; the opposite occurs for samples 4 and 5.

As regards granulometric distribution, comparison of the cumulative curves gives the same results as those of the frequency curves, in particular, a fairly good degree of sorting and a general decrease in grain size from the top deposits to the deepest ones; only two samples, 9 and 12, are a little coarser respectively than 8 and 11. These data fit the calculated mean grain diameters (tab. 2). However, both standard deviation and sorting coefficient confirm that all the analysed sediments are quite well sorted, especially samples 3 and 4, because they have the lowest σ_1 and $\sigma_\varnothing$ values. The Sk_1 values are always positive and indicate that the distribution has a more pronounced tail of fine material.

Results of heavy mineral analysis of three samples (2, 6 and 12) are shown in tab. 3. They have similar characteristics, such as a high percentage of garnets (minerals of medium resistance to chemical weathering, but very resistant to mechanical abrasion) and low contents of muscovite,

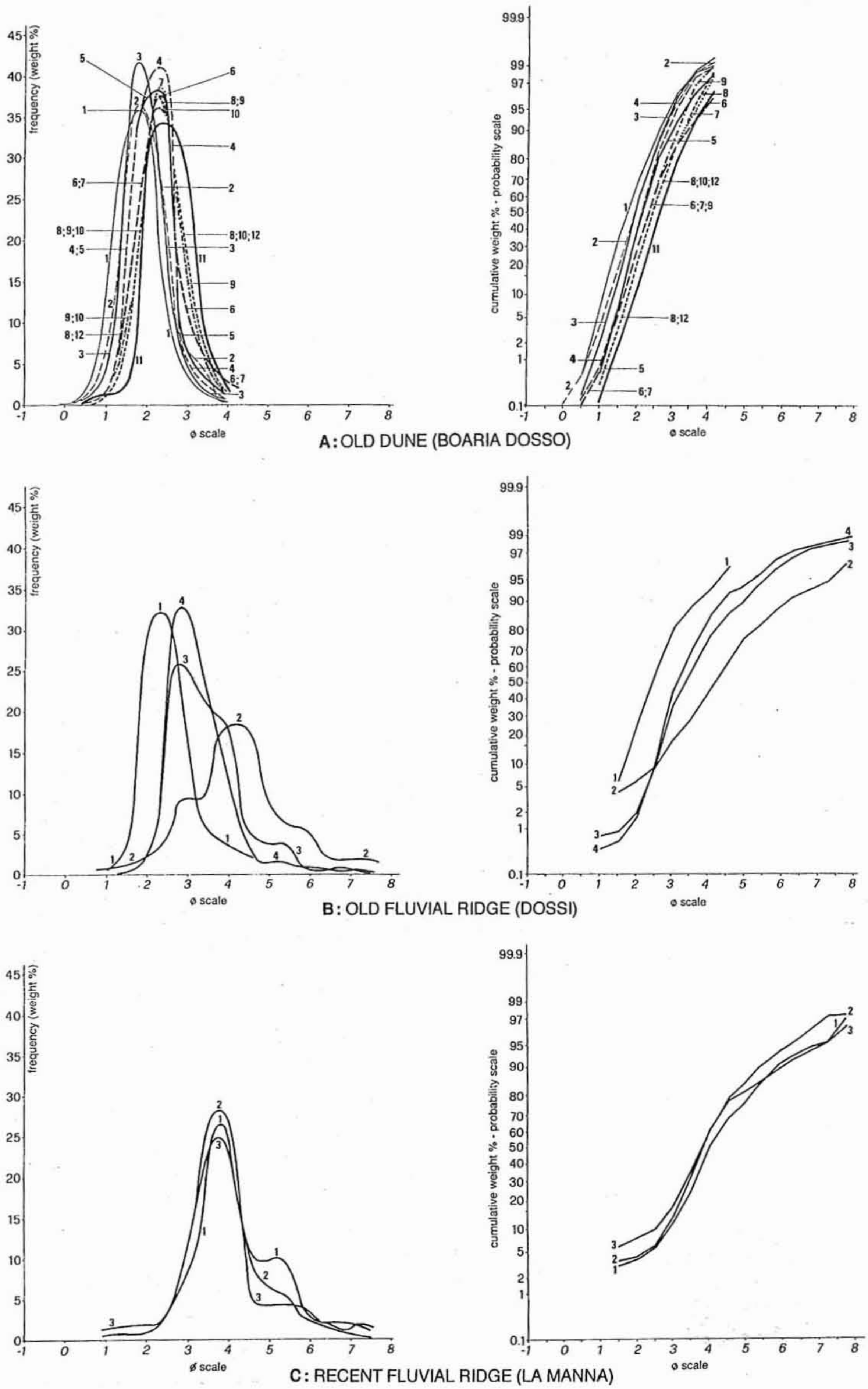


FIG. 7 - Frequency and cumulative curves obtained using results of granulometric analyses on samples collected from three different sites.

TABLE 2 - Main statistical parameters

D_m : mean grain diameter.
Sk_I : inclusive graphic skewness.
σ_I : inclusive graphic standard deviation.
$\sigma_\varnothing$: sorting coefficient.

Sample number	Dm (Ø)	Sk_I	σ_I (Ø)	$\sigma_\varnothing$ (Ø)
1	1.750	0.137	0.558	0.550
2	1.917	0.082	0.547	0.525
3	1.930	0.140	0.486	0.460
4	2.113	0.107	0.457	0.420
5	2.160	0.210	0.527	0.485
6	2.337	0.237	0.646	0.580
7	2.350	0.178	0.609	0.575
8	2.423	0.126	0.555	0.540
9	2.327	0.071	0.558	0.550
10	2.420	0.096	0.608	0.585
11	2.620	0.145	0.565	0.540
12	2.427	0. 121	0.568	0.540

A . Old «dune» (Boaria Dosso)

Sample number	Dm (Ø)	Sk_I	σ_I (Ø)	$\sigma_\varnothing$ (Ø)
1	2.480	0.232	0.773	0.680
2	4.190	0.116	1.481	1.310
3	3.453	0.298	0.923	0.870
4	3.220	0.329	0.785	0.670

B. Old fluvial ridge (Dossi)

Sample number	Dm (Ø)	Sk_I	σ_I (Ø)	$\sigma_\varnothing$ (Ø)
1	4.197	0.295	1.251	1.065
2	3.963	0.245	1.052	0.905
3	4.040	0.233	1.461	1.165

C. Recent fluvial ridge (La Manna)

biotite and chlorite (non-durable minerals which are first eliminated by selective aeolian removal owing to their lamellar structure (Mycielska-Dowgiallo, 1992, 1993)). These conditions are typical of aeolian environments because of the repeated reworking and redeposition of sediments. The amounts of epidotes (which have medium resistance to chemical weathering) and total percentages of rutile, sillimanite, staurolite, tourmalines and zircon (all durable minerals) are also significant because, in the case of mechanical abrasion, they respond with enrichment, like garnets. However, detailed analysis of this mineral distribution will be made later in the conclusive discussion, when all the results obtained from the whole investigation will be compared.

B - Old fluvial ridge (Dossi)

The four samples collected at Dossi have differing characteristics: 1, 3 and 4 are composed of silty sand and have a fairly good degree of sorting (particularly 1 and 4, which have the lowest σ_I and $\sigma_\varnothing$ values, as indicated in tab. 2). Sample 2 is composed of sandy silt and is poorly sorted.

Fig. 7 shows their frequency curves: 1 is unimodal, whereas 2, 3 and 4 are bimodal, with small secondary modes in the very fine fraction. 1 and 4 are highly peaked, but 1 has a maximum in the 2.0-2.5 Ø fraction, while 4 has it in the 2.5-3.0 Ø fraction, like 3. Sample 2 is less leptokurtic than the others and has its maximum in finer sediments (4.0-4.5 Ø). These results indicate that 1 is coarser: this is also confirmed by comparing the cumulative curves (fig. 7) and mean grain diameters (tab. 2). The positive Sk_I values indicate that all the samples have a more pronounced tail of fine sediments, particularly evident in the frequency curves.

Fig. 7 also reveals the dynamics of the processes which formed these deposits: sediments transported by suspension, saltation, or surface dragging and rolling are found in all samples except 1, which is lacking in the third mentioned population of grains. In any case, dragged materials, when they occur, are not very abundant.

Samples 1 and 4 were subjected to heavy mineral analysis (tab. 3). 1 has a very high content of garnets (35.2%) and little muscovite, biotite and chlorite (7.4%). Instead, in 4 the percentage of the mica group minerals is a little higher (10.3%), but garnets are not so abundant (12.0%). However, both samples have significant percentages of other resistant minerals: rutile, sillimanite, staurolite, tourmalines and zircon (7.5% of volume in 1 and 8.2% in 4), while the content of epidotes is 9.4% in 1 and 9.2% in 4. Amphiboles are also plentiful (14.2% in 1 and 20.8% in 4): amphiboles and pyroxenes are less resistant to chemical weathering and mechanical abrasion than other heavy minerals, and so they generally decrease in deposits subjected to repeated redeposition.

C - Recent fluvial ridge (La Manna)

The three samples collected at La Manna are composed of silty sand.

Their frequency curves (fig. 7) are leptokurtic, with the main maximum in the 3.5-4.0 Ø fraction; their peaks do not reach very different values (minimum 24.87% to maximum 28.18%). Samples 2 and 3 are unimodal, whereas 1 is trimodal with two secondary modes in the fine fraction, respectively in the 5.0-5.5 Ø (10%) and 7.0-7.5 Ø (1.8%) fractions. Sediment distribution always moves towards the finer material, as may also be observed from the positive skewness indexes (tab. 2). The degree of sorting is moderate, as shown in both frequency and cumulative diagrams and confirmed by the σ_I and $\sigma_\varnothing$ values.

The cumulative curves (fig. 7) reveal that all three samples are composed of grains transported by saltation, suspension, and surface dragging and rolling (this third population less abundant) and sample 2 is coarser than 1.

Heavy mineral analysis of samples 1 and 3 (tab. 3) reveals a high percentage of components with lamellar structure (61.6% in 1 and 50.3% in 3) and a low percentage

TABLE 3 - Results of heavy mineral analysis

* sample number
** per cent volume

		Old «dune» (Boaria Dosso)		Old fluvial ridge (Dossi)		Recent fluvial ridge (La Manna)	
Minerals	*No. 2	*No. 6	*No. 12	*No. 1	*No. 4	*No. 1	*No. 3
Heavy mineral content of the sample	**3.20	**5.83	**4.11	**2.41	** 1.70	**2.39	** 1.92
Amphiboles	** 22.2	** 17.0	** 17.7	** 14.2	** 20.8	** 9.0	** 11.3
Andalusite	2.0	1.7	2.1	0.4	0.6	0.2	0.1
Apatite	1.1	1.7	1.7	1.1	2.1	0.3	0.4
Biotite	2.0	2.5	2.5	3.1	3.5	9.5	5.9
Carbonates	7.0	1.5	2.7	0.0	9.7	10.6	14.4
Chlorite	2.8	2.7	4.0	2.6	4.1	8.5	7.0
Epidotes	6.1	7.2	6.9	9.4	9.2	3.6	5.9
Garnets	26.0	36.5	32.3	35.2	12.0	2.7	6.6
Kyanite	3.7	2.7	4.0	2.2	1.9	0.9	0.9
Monazite	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Muscovite	0.6	0.2	0.4	1.7	2.7	43.6	37.4
Phosphates	0.2	0.0	0.0	0.2	0.3	0.1	0.1
Pyroxenes	2.4	2.0	1.7	2.0	2.5	0.8	1.3
Rutile	0.9	1.0	0.2	1.5	1.1	0.7	0.6
Sillimanite	0.4	0.5	0.2	0.7	0.8	0.1	0.1
Staurolite	2.6	2.5	2.3	2.6	3.0	1.2	0.7
Topaz	0.0	0.0	0.0	0.7	0.6	0.0	0.0
Tourmalines	4.2	3.5	3.4	2.0	3.0	0.8	1.3
Zircon	0.2	0.2	0.2	0.7	0.3	0.2	0.1
Not identified	0.6	0.5	0.4	0.7	1.0	0.6	0.9
Opaques	15.0	16.1	17.1	19.0	20.8	6.6	5.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

of garnets (2.7% in 1 and 6.6% in 3). The total contents of other resistant minerals are also low (3.0% in 1 and 2.8% in 3).

CONCLUSIVE DISCUSSION AND INTERPRETATION OF RESULTS

All the results allow interpretation of the transport dynamics and depositional processes of the examined sediments.

In view of its shape and the granulometric characteristics and mineral composition of its sands, the *hill of Boaria Dosso* may be considered an aeolian dune. The similar degree of sorting and grain size of the twelve samples indicate that the dynamics of the process which accumulated these deposits did not vary greatly. The low σ_1 and σ_ϕ values also reveal that the sediments were subjected to selective removal due to wind flow, and the cumulative curves show that they were mainly transported by saltation.

The general increase in grain size from the deepest levels of the hill to the top ones (see comparison of granulometric curves) means that wind energy increased in the course of time, although slight variability may be observed in the lower part of the dune (see from samples 9 to 12). This is also confirmed by the values of the mean grain diameters (tab. 2).

The data of tab. 3 indicate that the deposit represented by sample 6 constitutes aeolian sand originating from transformed sand of the level of sample 12, as shown by the higher percentage of garnets in sample 6 (36.5%) than in sample 12 (32.3%). Similarly, there is an increase in the total percentage of other highly resistant minerals, rutile, sillimanite, staurolite, tourmalines and zircon, from 6.3% in 12 to 7.7% in 6. Another proof is the decrease in total contents of muscovite, biotite and chlorite from 6.9% in 12 to 5.4% in 6. However, the process of dune formation must have been fairly rapid, because the changes in mineral composition are not significant and the spectrum of the mineral composition is relatively wide. Conversely, sample 2 does not show any genetic relationship with the underlying deposits: it probably represents sediments borne by winds from a fresh source (e.g., flood deposits of the Adige river) and then added to aeolian ones; hence the lower content of garnets and higher percentages of amphiboles and pyroxenes, which are less resistant to chemical weathering and mechanical abrasion.

As regards the *old fluvial ridge (Dossi)*, comparison of the cumulative curves points to their dissimilarity as regards material transport. In fact, only the sediment of sample 1 was transported almost exclusively by saltation, like the deposits of Boaria Dosso; it also has quite a good degree of sorting, like sample 4, which means that both were subjected to selective processes.

The results of heavy mineral analysis on these two samples (tab. 3) confirm that the top layer is of aeolian origin. In comparison to sample 12, from the dune of Boaria Dosso, the uppermost deposit of the old fluvial ridge of Dossi has slightly higher percentages of both resistant minerals and components with lamellar structure. In particular, the total percentage of the mica group minerals is important in establishing the different degree of aeolization: in this case, the results (i.e. more abundant total contents of muscovite, chlorite and biotite in sample 1 from Dossi than in 12 from Boaria Dosso) indicate that the process which formed the top layer at Dossi did not last as long as that which accumulated the bottom deposit at Boaria Dosso, but the energy of the winds responsible for the formation of both was almost the same (cfr. cumulative curves).

As regards the old fluvial ridge, in comparison with the underlying layers, the uppermost sediments show distinct enrichment in garnets and epidotes as well as impoverishment in minerals with lamellar structure; there are also fewer non-resistant minerals (amphiboles and pyroxenes).

It is not clear whether sample 4 is of aeolian origin: the total percentage of muscovite, biotite and chlorite (10.3% in all) is not typical of wind-accumulated deposits because it is a little high, whereas the percentage of garnets (12.0%) is too low. However, comparison between sample 4 and the sediments collected at La Manna can help in interpreting them in the right way.

The sands of the *recent fluvial ridge (La Manna)* are not well sorted, have very high contents of the mica group minerals, and low amounts of garnets and epidotes, all indicating that they are deposits of a fluvial environment which accumulated without repeated redeposition. In particular, the high percentage of minerals with lamellar structure indicates that these layers probably belong to the extrachannel facies; conversely, channel deposits usually show impoverishment in this mineral group (Racinowski, 1974, in: Mycielska-Dowgiallo, 1995).

These considerations show that sample 4 of Dossi does not represent a flood deposit, owing to its far lower total amounts of muscovite, biotite and chlorite and its relatively more abundant contents of resistant components. It may be of aeolian origin, but the accumulation process which formed it must have lasted a very short time. Further proof is the percentage of amphiboles, higher in sample 4 from Dossi (20.8%) than in either sample 1 (9.0%) or 3 (11.3%) from La Manna. Although these minerals are not good representatives of aeolization, they are relatively more resistant to mechanical abrasion, and may thus be more abundant in aeolian than in flood deposits.

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