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MINERALOGICAL AND PETROLOGICAL CONTRIBUTION TO THE STUDY OF THE FALCONARA BASIN**

RIASSUNTO. — È stata studiata la serie stratigrafica di Falconara (Caltanissetta - Sicilia) con metodologie mineralogico-petrologiche e con successiva elaborazione dei dati ottenuti con analisi statistica (Q-mode). I risultati permettono di separare la serie in due parti nettamente distinte che corrisponderebbero a sedimenti tortoniani (unità inferiore) e messiniani (unità superiore). Le stesse conclusioni sono state suffragate anche dai dati geo-micro-paleontologici ottenuti per gli stessi campioni ed in fase di pubblicazione.

ABSTRACT. — The sedimentary Falconara section, south of M. Cantigaglione, about 3.5 km from Castello di Falconara in the south of Sicily, are here considered. All the samples were analyzed by X-ray, DTG, chemical and granulometric methods. The data were afterwards analyzed by Q-mode multivariate analysis.

The results are as follows: the clay minerals and feldspars are constantly present in low percentages, the percentage of quartz is constant in all the samples (25 % - 30 %), gypsum is sporadic and is linked to a secondary genesis. The more important variability is in the percentage of calcite (10 % - 45 %) and dolomite (0 % - 50 %): the former appears dominant at the bottom, while the latter becomes dominant in the upper part. Useful indications about the definition of the stratigraphic limit between Tortonian and Messinian age are found.

Introduction

All samples of Falconara stratigraphic section were analysed by X-ray, DTA, chemical and granulometric methods, in order to define the mineralogical and petrological composition and possible correlations among data. The data obtained were then analysed by multivariate factor analysis.

Mineralogical composition

Quantitative and qualitative mineralogical analysis were carried out «tout venant» and fractions, defined by granulometric methods. The fraction $< 4 \mu\text{m}$ were used in order to define the clay minerals.

The quantitative analysis carried out on quartz (CIPRIANI, 1958; RUNNELLS,

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1970), calcite and dolomite (CIPRIANI, 1958, 1961; ROYSE et al., 1971) and gypsum (BRIGATTI et al., in press). The feldspars were not defined because precise quantitative data were unobtainable: the quantity was insufficient.

Sample 45 separates the stratigraphic section into two (fig. 1): within each one the distribution of minerals is quite uniform. However the silicate minerals decrease progressively from the lower to the higher section. Gypsum, usually poor, is absent in the higher section; this mineral, never primary, is always in veins frequently perpendicular to the direction of the layers. Carbonates appear in

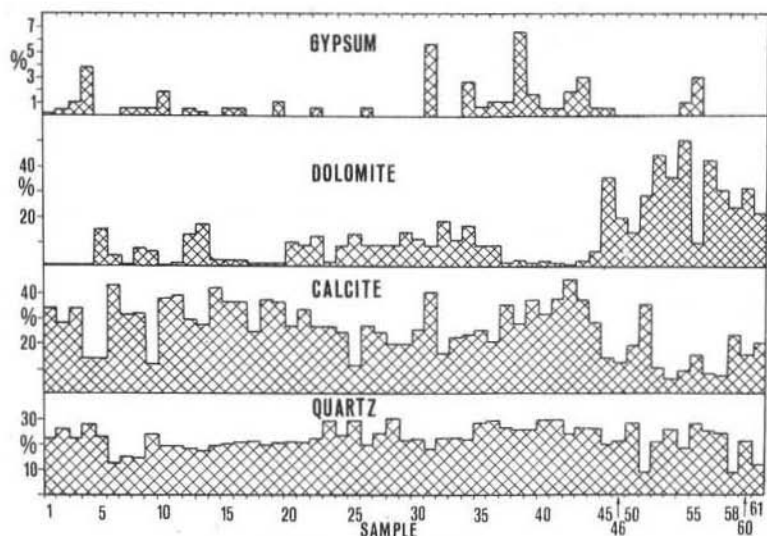


Fig. 1. — Histogram of the quantitative determination of quartz, calcite, dolomite and gypsum.

a typical distribution: calcite is prevalent in the lower section while dolomite is much more prevalent in the higher section. It is observed that when calcite predominates, dolomite is very little and viceversa.

Granulometric analysis and distribution of the principal minerals in the fractions

Regarding grain size analysis, the stratigraphic section is quite uniform, only in the higher levels is it possible to note the prevalence of the intermediate fraction. Silt is usually prevalent; in sample 38 only a few big crystals ($\varnothing = 0.5-1$ cm) of authigenic gypsum are present. In the higher section, sand is almost absent while clay fraction decreases. From the data obtained it could be pointed out that the basin was characterized by an environment of a calm sea, without a coarse grain sedimentation (fig. 2).

The regular distribution of minerals in a specific fraction has permitted the characterization of the paragenesis of three fractions considered.

In silt, quartz is very abundant, calcite diminishes while dolomite progressively increases, probably originating from normal precipitation. The feldspars, when present in a little quantity, are concentrated preferably in this fraction. The clay minerals obviously are concentrated in the clay fraction, while all the other minerals are scarce.

The sand appears to be made up of a predominance of calcite, whose origin, due to bioprecipitation, is confirmed by the large quantity of microfossils. In the sand, there is little quartz and dolomite is almost absent.

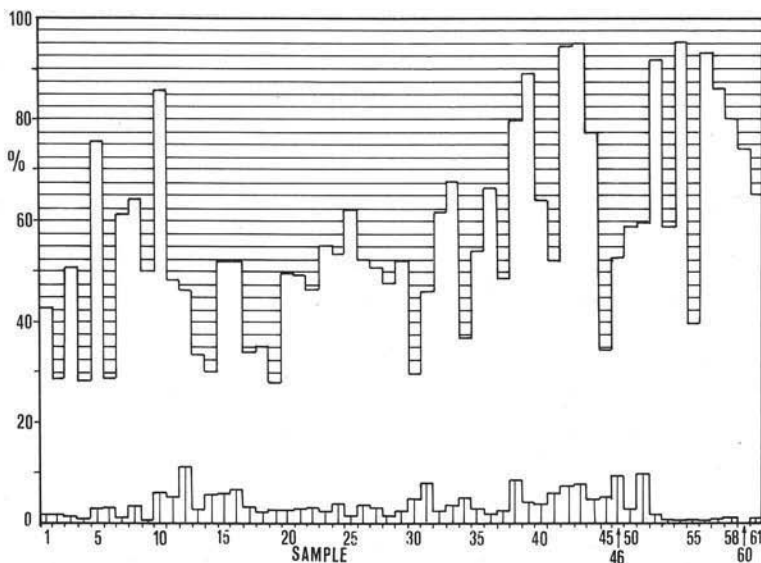


Fig. 2. — Histogram of the grain-size composition of the sediments. Sand: $\phi > 0.062$ mm (vertically-ruled field); silt: ϕ from 0.062 mm to 0.004 mm (white field); clay: $\phi < 0.004$ mm (horizontally-ruled field).

Chemical composition

Also the chemical data reported in table 1 confirm that the series can be separated into two well distinct parts.

The oxides defined show evidence of a clear variation of chemistry in the samples below level 45 from those over it.

The data would indicate, for the higher part of the series, a sudden rapid change of the environmental conditions of sedimentation in which a sediment with a high content of MgO is above all deposited.

Only CaO is present in all the series in a notably constant percentage. From the complete examination of the observations and the connected data it appears evident that dolomite, mineral to which MgO is completely connected, is of normal precipitation, the environmental conditions of the basin seem to be clear, where the materials of the upper levels were deposited were more favourable for a chemical precipitation rather than for a clastic sedimentation. In comparison,

TABLE 1
Chemical composition of the Falconara samples

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	CO ₂	H ₂ O ⁺	Str*	Ba*
1	36.29	.56	13.23	4.21	.11	2.13	20.04	1.28	1.43	.11	tr	15.01	5.61	820	144
2	40.79	.64	13.42	5.01	.09	2.52	16.51	1.10	1.78	.14	.23	12.67	5.09	695	140
3	36.03	.54	12.82	5.09	.07	2.29	19.39	1.19	1.47	.12	.46	15.25	5.27	1355	125
4	46.82	.75	17.02	6.33	.04	3.02	9.90	1.30	2.24	.10	1.77	6.50	4.20	500	206
5	38.72	.59	12.83	4.91	.07	3.64	17.25	1.43	1.72	.13	.00	13.21	5.51	640	165
6	28.51	.41	10.14	3.99	.10	2.27	26.07	.99	1.56	.11	.00	20.90	4.94	995	146
7	37.46	.58	13.44	5.05	.16	2.62	18.28	1.45	1.75	.11	.23	13.73	5.14	750	126
8	32.53	.48	11.33	4.43	.27	3.43	22.22	1.19	1.25	.10	.23	17.77	4.77	815	184
9	41.48	.66	14.72	5.40	.14	3.00	17.00	1.56	1.86	.11	.23	8.04	5.80	695	193
10	31.60	.45	11.08	4.05	.15	4.49	22.03	1.37	1.69	.11	.84	17.00	4.53	845	120
11	31.00	.42	10.97	3.30	.14	5.38	21.92	1.71	1.50	.09	.00	18.10	5.47	830	119
12	30.39	.43	10.80	3.96	.26	3.24	24.10	1.10	1.33	.11	.23	19.10	4.94	864	860
13	28.56	.36	10.02	3.32	.28	9.55	21.10	1.03	1.14	.09	tr	19.95	4.60	805	248
14	30.15	.42	10.62	3.81	.19	2.29	25.44	1.17	1.36	.11	.00	20.01	4.42	900	144
15	32.75	.47	11.37	3.79	.16	4.15	22.59	1.23	1.28	.10	.23	17.08	4.79	828	125
16	33.39	.48	11.74	4.16	.21	3.25	21.99	1.24	1.44	.10	.23	17.15	4.63	830	167
17	39.31	.60	14.12	4.87	1.47	3.35	15.51	1.07	2.13	.21	.00	11.80	5.55	648	125
18	34.32	.50	11.96	4.08	.21	2.37	21.95	1.27	1.81	.10	.00	16.94	4.51	840	170
19	33.39	.49	11.54	3.76	.19	2.52	22.36	1.71	1.36	.09	.23	16.77	5.61	864	170
20	32.76	.62	9.89	6.83	.24	2.49	22.17	1.57	1.81	.11	.00	16.29	5.20	890	161
21	31.02	.44	10.88	4.07	.26	3.17	24.24	1.09	1.25	.19	.00	18.52	4.87	1020	154
22	35.16	.49	12.22	3.93	.19	4.33	18.70	.98	1.63	.10	.23	17.20	4.83	745	163
23	40.05	.61	13.77	4.74	.22	3.00	17.15	1.21	2.07	.13	.00	11.95	5.10	670	171
24	36.10	.54	12.83	4.26	.23	3.46	18.90	1.41	1.58	.15	.00	14.71	5.82	700	195
25	41.63	.65	14.52	5.81	.30	4.01	13.48	1.28	2.10	.12	.00	10.97	5.14	570	143
26	34.57	.53	12.27	4.07	.34	3.47	22.32	1.22	1.62	.12	.23	15.70	3.53	807	310
27	35.88	.52	12.28	3.80	.21	4.86	18.92	1.73	1.52	.11	.00	14.60	5.59	970	148
28	41.59	.64	13.99	4.68	.20	3.19	15.82	1.26	2.14	.12	.00	12.11	4.25	660	150
29	37.76	.58	13.19	4.59	.28	3.62	17.73	1.43	1.78	.12	.00	14.96	3.97	670	170
30	35.78	.54	12.54	4.70	.31	3.39	19.63	.95	1.84	.11	.00	15.92	4.28	730	166
31	25.35	.38	8.74	5.25	.27	1.96	29.90	1.02	1.34	.13	2.56	21.50	1.61	1707	207
32	36.45	.59	12.31	4.93	.38	4.00	18.69	1.46	1.75	.11	.00	15.43	3.91	675	147
33	36.48	.57	12.74	5.37	.26	2.88	19.03	1.33	1.99	.10	.00	14.67	4.58	710	139
34	32.76	.48	11.04	4.14	.33	3.93	22.62	.97	1.59	.10	1.16	17.94	2.94	920	162
35	36.91	.53	11.62	3.93	.22	3.45	20.31	1.55	1.60	.10	.23	15.19	4.35	730	170
36	37.97	.63	9.49	6.81	.25	2.74	19.84	1.66	2.13	.11	.46	12.89	4.93	680	140
37	34.22	.61	8.54	5.79	.32	1.73	22.40	1.70	2.85	.11	.46	16.32	4.94	790	160
38	38.70	.61	12.88	5.02	.15	2.63	18.97	1.20	1.72	.11	3.02	13.01	1.98	705	146
39	31.81	.61	9.92	5.71	.41	1.74	24.20	1.73	1.67	.10	.70	16.91	4.49	795	130
40	35.36	.56	12.27	4.61	.15	2.74	20.76	1.39	1.46	.11	.23	14.98	5.59	730	240
41	32.88	.51	11.57	4.85	.20	2.72	23.16	1.16	1.27	.11	.23	16.83	4.51	795	150
42	28.87	.43	10.25	3.55	.31	2.51	26.90	1.09	1.01	.10	.84	20.07	4.06	910	139
43	33.40	.51	11.72	4.10	.20	2.77	22.82	1.15	1.25	.11	1.40	17.41	3.17	765	144
44	35.33	.53	11.88	7.31	.20	3.06	17.98	1.19	1.50	.11	.23	15.09	3.47	650	176
45	28.04	.39	9.43	4.15	.40	8.04	21.38	.76	1.25	.09	.23	22.77	3.05	625	154
46	38.81	.54	12.05	4.42	.15	4.52	18.58	.71	1.64	.09	.00	14.22	4.26	615	114
50	41.42	.57	12.38	4.85	.28	4.96	15.93	.68	1.98	.10	.00	12.38	4.48	595	200
51	21.38	.24	5.82	2.25	.40	6.92	29.53	.41	.82	.10	.00	28.73	3.40	830	100
52	25.77	.31	7.60	2.76	.19	12.65	19.73	.51	.99	.09	.00	25.54	3.86	382	68
53	31.60	.40	9.13	3.53	.13	11.90	18.49	.70	1.17	.09	.00	19.30	3.55	410	124
54	21.04	.24	6.04	2.15	.12	16.15	21.32	.65	.61	.08	.46	27.82	3.40	375	66
55	63.88	.16	3.18	1.50	.03	2.41	13.01	.64	.73	.09	1.40	11.06	1.91	445	43
56	27.10	.34	7.67	2.80	.07	15.23	17.84	.47	.85	.08	.00	23.60	3.95	335	88
57	35.96	.49	9.98	3.91	.15	10.46	15.73	.44	1.39	.10	.00	17.26	4.12	410	69
58	28.94	.38	8.34	3.12	.45	6.20	25.42	.60	.74	.13	.00	21.25	4.43	2630	133
60	29.00	.36	7.77	3.08	.45	10.28	21.29	.50	.37	.12	.00	21.75	5.04	3640	116
61	33.28	.43	9.19	3.60	.25	6.56	21.21	1.03	.68	.15	.00	18.72	4.91	8800	243

then, from the data from table 1 and fig. 1, it should be remembered that in sample 55 the notable difference between percentage of SiO₂ and the content of quartz is explained by observing the natural material opportunely prepared, using, the microscope (glass-amorphous phases).

The high percentage of MnO in n. 17 sample with respect to the general average of the series, is connected to the probable presence of oxides and hydroxides

of this element, not resolvable by X-ray methods. A possible connection of MnO with corresponding carbonate was not found with certainty, on the basis of the experimental methods used.

Q-Mode multivariate analysis

The statistical approach for grouping and discriminating the samples studied is the Q-mode multivariate analysis. This method, used in geological studies for the first time by IMBRIE and PURDY (1962), has been largely reported in numerous studies of statistical mathematics (HARMAN, 1970; DAVIS, 1973; SHAW and HARMAN, 1975).

With this method it is possible to explain some factors, amongst which a percentage of the total variance, specific to a determined group of samples.

In the present case eight eigenvalues (table 3) are extracted with a cumulative variance of 99 % and three of those were retained for rotation (table 3). F_1 , F_2 , F_3 are theoretical factors because no sample has a composition like theirs, and the communality, generally 0.9, for two samples only is between 0.8-0.9.

Besides the normal reciprocal plots (fig. 3) obtained from orthogonal factors, it is also possible to plot all samples in a triangular diagram (fig. 4), on which the three main factors are shown on the apexes. They were obtained after slight rotation from the original orthogonality and after carrying over to 100: in such a way that the weight of each factor of the cumulative variance is explainable and comparable with greater ease.

The same method of statistical analysis was used also considering as variables the quantitative percentage of some minerals of fig. 1 besides the oxides. The new discrimination was even more marked and used to better interpret the position of some samples that in the first diagram seemed to be located in a disorderly fashion.

Interpretation

In the diagrams of figs. 3 and 4 two clusters that come together are created: in one, the samples 1-44, in the other, the rest of the series up to the level 61.

The high number of variables used as discriminants makes the interpretation of the geochemical significance of the distribution and of the clusters determined in the various diagrams rather difficult. An explanation can be tried by examining the significance of the various factors, on the basis of which the various plots are made.

TABLE 2
Eigenvalues

N°	Eigenvalue	Cum.Var.
1	52.836250	92.70
2	1.620559	95.54
3	.743088	96.84
4	.447220	97.63
5	.309368	98.17
6	.265917	98.64
7	.189914	98.97
8	.156167	99.24

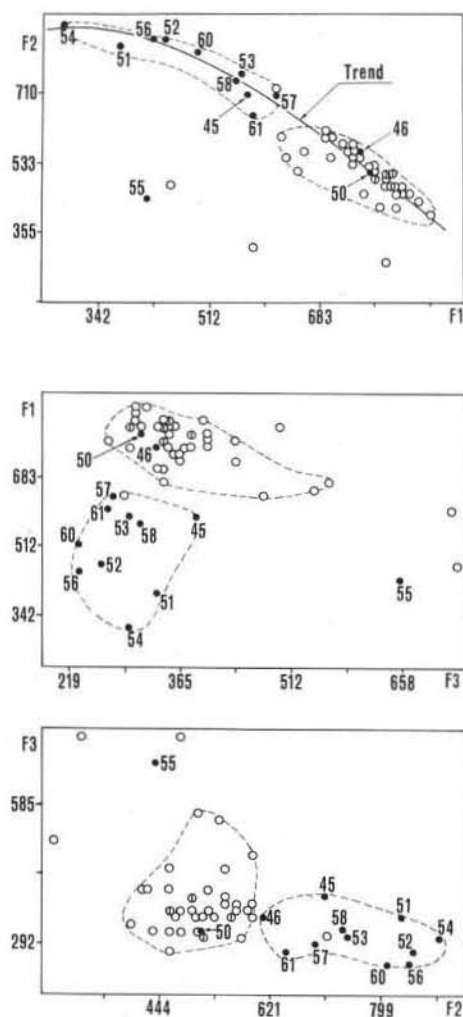


Fig. 3. — Plots obtained on the basis of three main factors. The cut circles indicate the position of various samples.

factor of CaO and CO_2 variables is due to the presence of a high percentage of calcite, while the remaining oxides are probably subordinate to a slight quantity of silicate minerals, mainly of a clayey nature. The samples under 44 concentrated in the cluster characterised by higher indices than factor 1 are in the diagrams.

On factor 2 the more important variables are: MgO , CO_2 , CaO , Na_2O (negative). The nature of such oxide indicates that, amongst the discriminating minerals, calcite is substituted by dolomite, becoming the more indicative mineralogical component of the grouping.

Factor 3 shows the signs of the discriminating importance of SO_3 , H_2O^+ (negative) and CaO , the last, being less important than the others. Factor 3 reveals

TABLE 3
Varimax factor score matrix

Var.	F.1	F.2	F.3
SiO_2	.148	.081	.301
TiO_2	.394	.014	.088
Al_2O_3	.366	.065	.056
Fe_2O_3	.309	.006	.172
MnO	.044	.091	-.007
MgO	-.191	.578	-.118
CaO	-.003	.397	.306
Na_2O	.421	-.076	.162
K_2O	.316	-.041	.127
P_2O_5	.157	.173	.129
H_2O^+	.420	.299	-.250
Sr	-.002	.111	-.020
Ba	.079	.040	.037
CO_2	-.137	.572	.177
SO_3	-.227	-.145	.779
Variance	50.169	31.762	14.911
Cum.Var.	50.169	81.931	96.842

On factor 1 the variables that have a greater influence are, in order of decreasing importance: H_2O^+ , CaO , TiO_2 , Na_2O , Al_2O_3 , Fe_2O_3 , CO_2 , SiO_2 and P_2O_5 (table 3). On the basis of the already determined mineralogical composition, the notable importance on this

a slighter discrimination than the other two, distributing the samples almost without identification. The scarce importance of this factor is above all due to the irrelevant presence of SO_3 , linked to gypsum and hardly ever partners determinable or significative quantities.

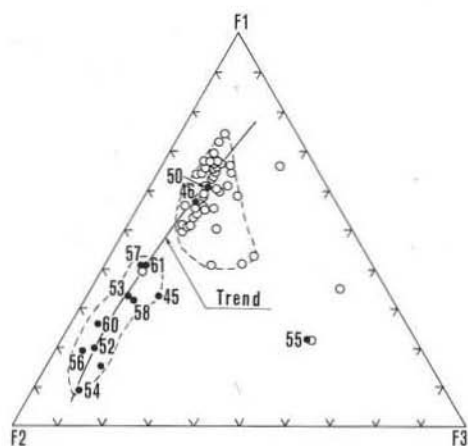


Fig. 4. — Triangular plot relative to the three main factors (F.1, F.2 and F.3) after rotation from the original orthogonality and normalization.

The second cluster in the upper part of the series is defined by higher values in F.2 and it joins those samples in which dolomite, progressively but in an evident way, becomes the most important mineral. In F.2, F.2 diagram the position of the latter cluster also probably shows signs of the decreasing amount, in the samples, of the clay minerals. This reduction is chemically confirmed by the lower percentage of Na_2O , K_2O , Al_2O_3 and SiO_2 , and consequently by the minor discriminating weight on factor 2 of the variables corresponding to these oxides.

The position of some samples, outside the two principal clusters is explained by an uncertain variability of the amount of some oxides with respect to the average values specific to the samples contained in the clusters.

A confirmation of the interpretation of F.1, F.2 diagram is given by a trend along which nearly all the analysed samples are distributed. In fact, to the extremity of the trend, towards the higher indices of factor 2 the samples with a more progressive and higher content of dolomite are positioned, while with increases of the other factor the samples containing a larger quantity of calcite and clay minerals are defined.

On the other diagrams, F.1, F.3 and F.3, F.2 (fig. 3) given the scarce discriminating incidence of factor 3, the two clusters widen, and no variability trend is recognisable.

On these plots only the samples, which in diagram F.1 are separated from

On the basis of the various factors, an interpretation of the groupings that part the diagrams (fig. 3) and the geochemical significance of the discrimination can be attempted.

In plot F.1, F.2 (fig. 3) which is more indicative and on which, besides the two clusters, a clear trend of variability is seen, the position of the clusters indicates that for the samples characterized by a high value on a factor, low indices correspond for the other. Such behaviour connected to the natural chemistry of the variables which influence the two discriminating factors, allows the identification of notable quantities of calcite, as discriminating minerals, in the sediments of the lower part of the series.

the principal clusters, are characterized by the higher indices on factor 3. Such samples in every series have a higher content of gypsum.

Regarding the triangular diagram of fig. 4, the weight of the variables which influences the three factors is distributed in a slightly different way, due to their small rotation with respect to the original orthogonality and after carrying over to 100. The effects of such operations condition, in particular, factor 1, from which a movement towards the other two comes about due to the discriminating influence of some variables such as SiO_2 , CaO and CO_2 . On this diagram the effects of the different distribution of the weight of some discriminants are irrelevant: the two clusters, evident in the reciprocal plots of fig. 3 maintain not only their own individuality but the same position above all in comparison with factors 1 and 2, the samples for the most part joined to factor 3 also have a similar behaviour and, similarly, the variation trend identified on plot F.1, F.2 is recognisable.

These similarities could indicate a limited discriminating importance on factor 1 of the SiO_2 variable and probably, of the scarce silicate minerals of the clay type which would be connected to it.

Such hypothesis would implicate that at least one part of the principal oxides which influence factor 1 would not be linked to silicate minerals or to others with crystalline structures, identifiable with normal diffractometric methods. It would nevertheless deal with quantity, variable but always scarce, of oxides and hydroxides present under colloidal form which would be sedimented either during the normal cycle of deposition or it would be connected to the phenomena of percolation with cementing, during the diagenesis process.

Furthermore, on the triangular diagram, the almost total placing on factor 2 of the weight of the variables MgO , CaO and CO_2 concentrates the discriminating action on only one parameter due to the principal carbonates, contrary to what happens on the reciprocal plots, on which the same discrimination is subordinate to factor 1 and 2.

Mineralogical-petrological considerations

Up to the present, exact stratigraphic dating and defining on the basis of only one mineralogical-petrological composition of a material, has been very rarely reached, in particular when this is presented under the form of sediment with grain sizes prevently fine and scarcely cemented.

On the samples of the Falconara series it is attempted, simultaneously examining micropaleontological data to recognise eventual discriminating elements that could supply valid indications about the definition of the stratigraphic passage from the Tortonian to the Messinian age.

On the basis of the mineralogical-petrological composition it was possible to subdivide the series examined into two well distinct parts, which would correspond to the Miocene intervals.

For the first, the sample that in stratigraphical succession would be set apart,

always contains the higher percentage of calcite, while in the Messinian age it would have a progressive and sudden substitution of the calcite from dolomite. All the minerals of the silica present a variable quantitative distribution in the two recognised stratigraphical units.

Gypsum is not revealed as a discriminating component as it is present in irregular intervals and always in a poor percentage. Its irrelevant importance is also connected to its non-primary genesis.

It is nevertheless emphasised that above considerations, which perfectly agree with the conclusions of a micropaleontological character, to the present state of the studies, are valid only for the Falconara section.

It is not possible to generalise the mineralogical-petrological observations with sediments in other zones, even if for some, above all Emilian, partially known data, do not contrast with the specific conclusion of the study of the Falconara series. It would be suitable to apply the methods used here, to other stratigraphical series, where it may be possible to generalise to other areas the conclusion given for the Falconara series.

It should also be emphasised that the data regarding the distribution of the clay minerals in Falconara, are not in great accordance with those indicated by CHAMLEY, 1976. This Author, for whom there exists, in Sicily, a difference in the paragenesis of the Tortonian and Messinian clays, distinguishing the two periods on the basis of minor content of the smectite on the older sediments in comparison with the stratigraphically more recent illite, chlorite, kaolinite and attapulgite, in order of importance.

At Falconara the distribution of these minerals undergoes a notable variation because, besides showing an evident tendency to disappear towards the high part of the series they are never formed as principal phyllosilicates from smectite and attapulgite while quantitatively kaolinite and illite are almost always predominant.

This paragenetic disagreement could be attributed to the non-identity of the series studied or to the nongeneralising homogeneity of the mineralogical composition for materials belonging to the same geological period and deposited in basin or in zones of the same basin, even if not excessively distant from each other.

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