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PETROCHEMICAL INVESTIGATIONS ON THE « CENERIGNEISSES » OF M. ZEDA

(LAGO MAGGIORE, NOVARA, ITALIA)

ABSTRACT. — A series of samples, systematically collected across the most important horizon of the « Cenerigneisses » cropping out on the southern part of M. Zeda, have been analyzed.

TiO_2, Fe_2O_3, FeO, CaO, Na_2O, K_2O, were determined; then the normative Ab/An ratio and the oxidation ratio were calculated.

The high homogeneity in chemical composition of the « Cenerigneisses » suggests the hypothesis of a differential anatexis of an originally inhomogeneous sedimentary series.

RIASSUNTO. — Sono state eseguite analisi chimiche parziali su una serie di campioni raccolti sistematicamente attraverso i due più importanti orizzonti di « Cenerigneiss » affioranti sul versante meridionale del M. Zeda.

Sono stati determinati TiO_2, Fe_2O_3, FeO, CaO, Na_2O, K_2O; sono stati quindi calcolati il rapporto Ab/An normativo e il rapporto di ossidazione.

La notevole uniformità dei caratteri chimici dei « Cenerigneiss » costituisce una prova della loro origine anatettica a partire da materiale sedimentario inomogeneo.

In the Strona-Ceneri zone several elongated bodies of peculiar gneisses, called « Cenerigneisses » (Reinhard 1934, Bächlin 1937, Boriani 1970a, 1970b), crop out. In this paper the two main horizons that occur on the western side of Lake Maggiore are considered. The first layer is found in continuity from M. Faiè, where at the intersection with the Pogallo Line it grades into the heterogeneous migmatites of the Mergozzo-Gravellona zone (Boriani-Peyronel Pagliani 1968), up

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to the Cannobina Valley. This subvertical elongated body strikes N 60° E; its maximum thickness is about 2200 m between Steppio and La Pascola, in the vicinity of M. Todano. In the central and northern part these « Cenerigneisses » appear almost granular, medium to fine grained, and are considerably homogeneous, more or less strongly lineated. Over a thickness of about 700 m, along the southern margin there are many intercalations of other rock types; there « Cenerigneisses » show more pronounced schistosity and are alternated with micaschists and paragneisses rich in quartz.

Xenoliths are the most evident mesoscopic character: they generally show a concentric zoning with a calc-silicate core surrounded by a shell of fine grained gneiss (Boriani-Clerici Risari 1970). The amphibolite inclusions are rare.

The maximum diameter ranges from 10 cm to 1-2 m; the shape too is variable: elongated and flattened in the schistose and more spherical in the pseudogranular « Cenerigneisses ».

The northernmost horizon, about 800 meters thick, crops out from A. Prà in the Pogallo Valley, where it is abruptly cut by the Pogallo fault, as far as Socraggio, a village in the Cannobina Valley.

The mesoscopic features of this horizon are very similar to those of the « Cenerigneisses » of the former, but, as this one is thinner, the pseudogranular types are lacking: the fine grained gneisses and paragneisses intercalated in tight folds are more abundant and the xenoliths are very flattened.

Microscopic characters.

The mineral assemblage consists of: plagioclase (22% An), quartz, biotite, muscovite ± K-feldspar ± garnet ± kyanite. Constant accessories are: apatite, zircon, and opaque minerals, while sphene and epidote are always absent.

A peculiar feature of the microstructure is the presence of two generations of the fundamental minerals, with the exception of quartz; the first generation minerals are coarser than those of the second (Boriani 1970a, 1970b).

The only difference between the two horizons is that the sizes of the second generation minerals of the northernmost horizon are greater than those of the principal one.

The meso- and microscopic characters show that these rocks are tectonites, and that their present appearance is due to deformation of an originally medium to coarse grained rock. The presence of xenoliths with reaction margins, the mineralogical composition and the noticeable homogeneity of the rock over a large area, support the hypothesis that the « Cenerigneisses » are the result of anatexis from a series of sedimentary rocks with marl intercalations.

Petrogenesis.

Bächlin (1937), in his study of the M. Ceneri region, described these rocks as « Mischgneise », i.e. derived from the enclosing paragneisses with minor introduction of igneous material. On the basis of several analysis he found the « Cenerigneisses » very similar to biotite-plagioclase gneisses and to « Biotithornfelsgneisses », and noted that these rocks are associated with « Cenerigneisses » throughout the investigated area.

The « Cenerigneisses » could therefore have been produced by the metasomathic addition of Al, K, Na and subtraction of Mg, Ca, Fe. Their « glomerogranular » texture could have been due to a lamination process in mesocatazonal condition, on plagioclase and biotite and not on quartz, as the latter is never present finely granulated. According to Bächlin the lack of granulated quartz is a demonstration that the lamination was not a true cataclastic process.

Also the peculiar shape of xenoliths is the result of rocks of different composition, once present in the material from which the « Cenerigneisses » are derived.

Reinhard (1964) retains that the « Cenerigneisses » are true paragneisses without any addition of igneous material and their texture represents the initial stage of a blastic process in a strictly defined P-T range. The fine granulation of plagioclase is the result of a « frozen » process of recrystallization.

According to Boriani (1970a) the present features of « Cenerigneisses » are due to anatexis of material derived from a series of shales and graywackes with marl intercalations, recrystallization from the melt of a rather coarse-grained migmatitic rock of unknown texture with calc-silicate xenoliths. Later a severe deformation, that

TABLE I. — *Chemical composition and certain ratios of « Cenerigneisses ».*

no.	Ca	Na	K	Ab%	An%	Ab/An	$Fe^{3+}_{tot.}$	$Fe^{3+}_{r.}$	Fe^{2+}	R.ox.	Ti
1	1.0600	4.0600	3.7900	87.4000	12.6000	6.9400	4.2900	1.0900	2.8800	25.7500	.4800
2	1.1600	3.7600	3.7100	85.4400	14.5600	5.8700	5.8500	1.8400	3.6100	31.2300	.7600
3	.9300	3.1100	4.4100	85.8300	14.1700	6.0600	4.5400	1.6000	2.6500	35.0900	.5500
4	1.3300	3.3200	4.2000	81.8500	18.1500	4.5100	4.0600	2.3300	2.4600	45.5400	.5500
5	2.3300	6.6000	1.6700	83.6800	16.3200	5.1200	2.5600	.9700	1.4300	37.9800	.3500
6	3.7400	4.5500	2.3700	68.7600	31.2300	2.2000	6.1100	3.1000	2.7700	49.5400	.5400
7	2.1500	4.5000	3.1700	79.0900	20.9100	3.7800	5.5800	1.5700	3.6100	27.8700	.7300
8	.9400	2.5000	4.4100	82.7700	17.2000	4.8100	6.1400	2.4600	4.2200	34.8200	.7300
9	1.7700	4.7400	3.1300	82.9000	17.1000	4.8500	5.0400	1.3200	3.3500	26.2400	.5700
10	1.0800	3.0000	4.1500	83.3900	16.6100	5.0200	5.5800	1.5700	3.6100	27.8700	.6300
11	1.0700	3.4800	3.7800	85.4600	14.5400	5.8800	5.4600	2.7200	3.3700	32.7000	.6100
12	1.2000	3.5800	3.9700	84.3600	15.6400	5.3900	5.7500	1.5100	3.8200	25.4900	.7400
13	.9400	3.6700	3.9000	87.6100	12.3900	7.0700	4.9700	1.4000	3.2200	28.4800	.4800
14	1.3400	3.9300	3.7800	84.1300	15.8700	5.3000	4.7100	1.6100	2.7900	34.1800	.4300
15	1.3200	4.0200	3.9500	84.6500	15.3500	5.5100	5.1000	1.6400	3.1200	32.4000	.6200
16	1.0800	3.6100	4.3100	85.9300	14.0700	6.1100	5.7200	2.1000	3.2600	42.2100	.6000
17	1.0600	3.8900	3.8100	86.8900	13.1100	6.6200	5.4700	1.4200	3.6500	26.0900	.6300
18	1.0700	4.0400	3.8700	87.2200	12.7800	6.8200	4.6100	1.0800	3.1800	23.3700	.5900
19	1.3300	4.2800	3.8700	85.3500	14.6500	5.8300	5.1700	.9600	3.8800	18.2400	.6400
20	1.2000	4.0000	4.0700	85.6800	14.3200	5.9800	5.5400	1.4600	3.6800	25.8600	.6900
21	.7600	3.9800	4.6400	90.3400	9.6600	9.3500	4.7500	1.2800	3.1300	26.8500	.5400
22	2.2400	4.6700	3.9600	79.0300	20.9700	3.7700	2.2300	.2500	1.7800	10.7900	.2500
23	2.8500	5.4300	3.2000	77.5000	22.5000	3.4400	5.9500	1.8500	3.6900	30.7500	.6500
24	2.7500	4.2200	3.7500	73.5400	26.4600	2.7800	7.0200	2.5400	4.0400	36.3100	.5800
25	2.7700	3.2700	3.6500	68.1100	31.8900	2.1400	4.5000	.5500	3.5600	12.3700	.5700
26	2.3200	4.1800	3.5500	76.5400	23.4600	3.2600	5.1700	1.1400	3.6300	22.8700	.6600
27	1.2900	2.4200	3.2500	77.2600	22.7400	3.4000	6.6000	1.5300	4.5700	22.6000	.8300
28	1.3500	4.2200	4.1500	84.9900	15.0100	5.6600	4.0000	.9400	2.7600	23.7100	.5100
29	1.3500	4.1400	4.0700	84.7200	15.2800	5.5400	7.1300	3.2500	3.5000	45.5600	.6700
30	2.9300	3.7100	3.6400	69.6400	30.3600	2.2900	5.0200	2.5100	2.2600	50.3100	.5900

caused the formation of a new schistosity and a lineation, affected the rock body and probably created large folds throughout the whole complex. A static phase with partial recrystallization of the minerals and formation of equilibrium textures occurred lastly.

The present hypothesis is that, as the severity of this deformation was not homogeneous from site to site, it created different textures in the various parts of the body.

Two series of samples, from the principal and the second horizon, including schistose intercalations, were partially analysed, in order to check this hypothesis petrochemically and verify that the apparent homogeneity of the rock corresponds to a true chemical homogeneity and to characterize the schistose inlayers.

In the first horizon 22 samples were collected on the foot-path between Steppio and La Pascola, while the 8 analysed samples of the second horizon come from the Pogallo Valley on the Cicogna-Pogallo mule-track.

The procedure followed in collecting these samples was to take them one hundred meters from each other in real thickness. Then partial analyses by wet chemical methods were carried out, determining the following oxides: CaO, Na_2O, K_2O, Fe_2O_3, FeO, TiO_2. From the weight percentages, An normative, Ab/An, and oxidation ratio were calculated (Tab. I) and plotted, together with the other results of the analyses, in diagrams with in abscissae the constant distance between the samples (100 m of actual thickness).

The arithmetic mean, variance, standard deviation, standard error were calculated for each series of data by means of a suitable computer programme; statistical parameters were then recalculated eliminating aberrant data according to Chauvenet's criterion.

Factor analysis was performed on the set of data obtained from 30 samples. A programme by Ondrick and Srivastava (1970) for Q-mode and R-mode factor analysis has been run. The programme, starting from the correlation between samples, computes parameters suitable to recognize the contribution of each element analized (R-mode) or of each sample (Q-mode) to the total variation of the sample.

In the present case R-mode analysis gives no help as it emphasizes only foreseen correlation among variables.

Q-mode analysis is more interesting as it points out the contribution of each sample to variation factors and clarifies complex interrelations among samples of different nature. The results of calculations are given here in the form of graphic displays where each point represents one sample in the plane defined by two main variation factors; as three factors had been computed, three plots have been given (fig. 1).

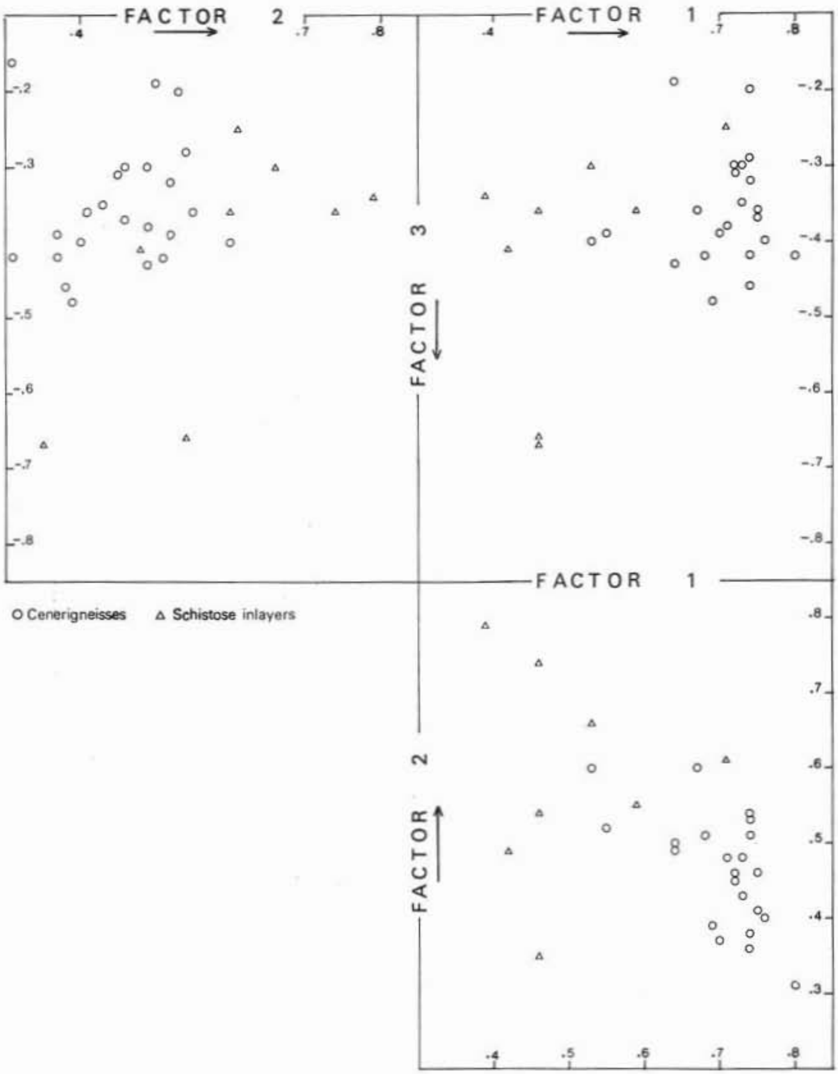

Fig. 1. — For explanation see text.

In the plots most of the points representing « Cenerigneisses » are clustered together; the « Cenerigneisses » of the first horizon cover a particularly small surface; on the other hand the points representing intercalations, are markedly spread toward lower values of F1 and higher values of F2.

The TiO_2 distribution (fig. 2) shows notable homogeneity, both for the first and the second horizon. The calculated average is 0.014. The distribution of this element does not seem to be notably distinctive about the difference in composition between the « Cenerigneisses » and the schistose intercalations. It is to be noted that «Cenerigneisses» never contain sphene, so all the titanium present in the rock belongs to biotite and ilmenite.

More indicative is the CaO distribution (fig. 3); in fact the graph of the first horizon emphasizes the schistose intercalations (samples 5-6-7-32), that show a higher Ca content than the « Cenerigneisses ». The calculated average is 1.624, the variance is 0.59; it is noticeable that the Ca contained in « Cenerigneisses » has an even and homogeneous value. As « Cenerigneisses » contain calc-silicate xenoliths, we could expect the distribution of Ca to be inhomogeneous, and the fact that it is fairly regular supports the hypothesis of an anatectic homogeneization of the pre-existing rock.

Also the distribution of Na_2O brings out the schistose intercalations (fig. 3) where Na content is higher than the average (average 3,963, variance 0.653). Also in the granular « Cenerigneisses » there are some oscillations around the average values, of Na content, but it should be noted that these small variations can be related to the same variations in Ca content: they coincide with correspondingly small variations in the normative plagioclase.

The K_2O graph shows (fig. 3) that the distribution of this element is very homogeneous and very close to the average (average 3.739, variance 0.361). An increase of K-feldspar corresponds to a decrease of normative plagioclase and viceversa.

Normative albite and anortite have been calculated from CaO and Na_2O weight percentages; the ratio Ab/An (fig. 3) gives a very irregular curve, because this type of representation notably amplifies the variations of An content. In « Cenerigneisses » the Ab/An ratio (average 5.043, variance 2.733) is always higher than the ratio quoted by Von Platen and Höller (1966) as the minimum for the beginning of

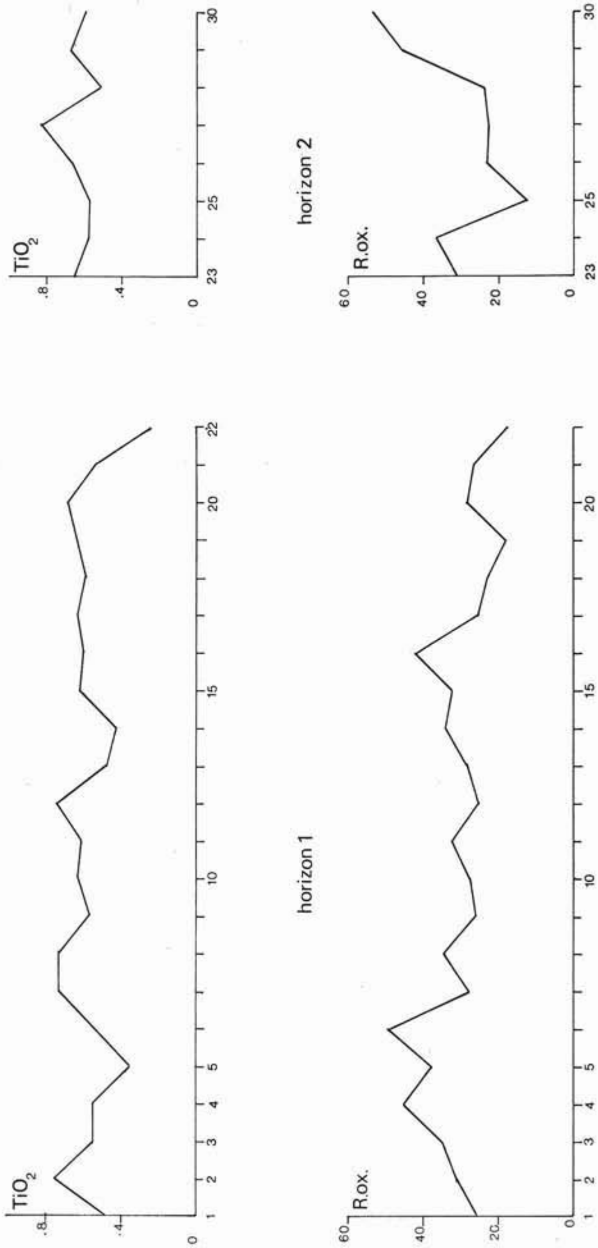

Fig. 2. — TiO_2 and oxidation ratio variation in the 1st and 2nd horizon.

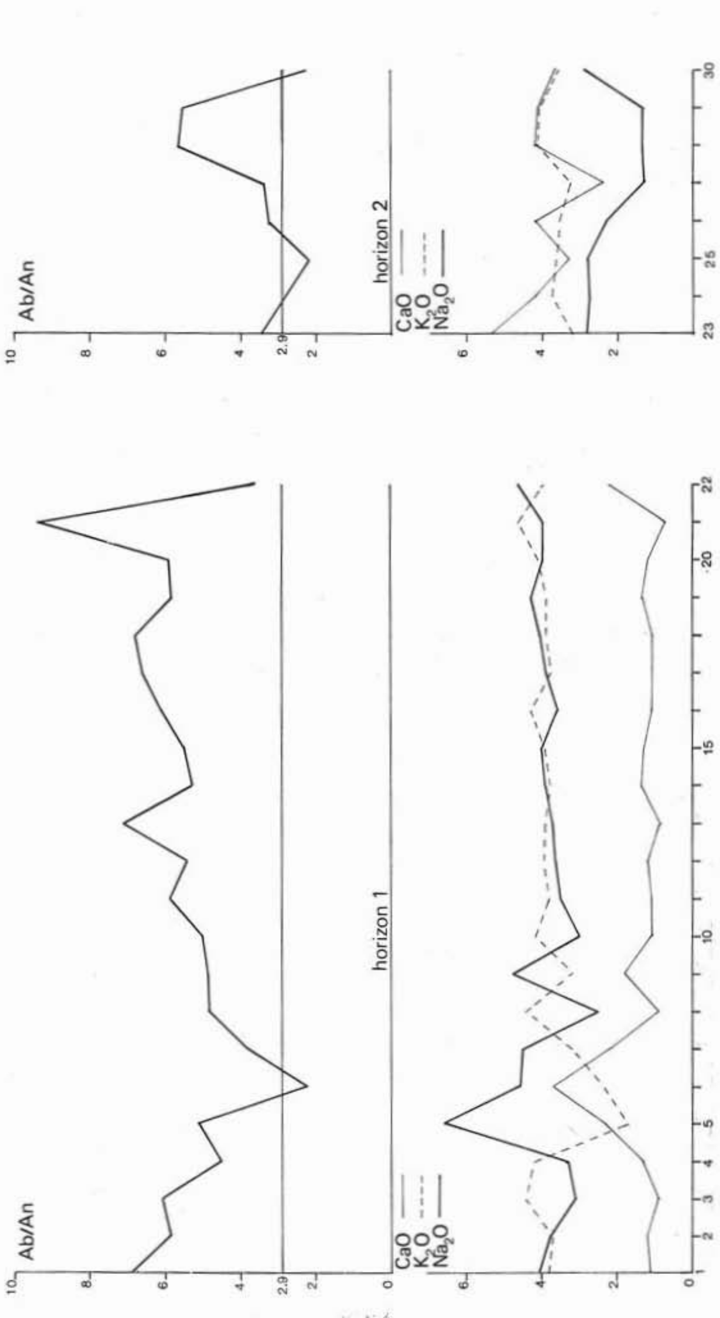

Fig. 3. — Ab/An, CaO, K_2O, Na_2O variation in the 1[st] and 2[nd] horizon.

anatexis (Ab/An 2.9), in amphibolite facies at high pressure (kyanite type of metamorphism shown by these rocks).

The ferric iron content has been calculated from the total iron by spectrophotometric method, and from ferrous iron by titration with potassium permanganate; the oxidation ratio has been calculated using the formula (Chinner 1960):

$$\text{mol}\ \frac{2\,Fe_2O_3 \times 100}{2\,Fe_2O_3 + FeO}$$

The graph (fig. 2) shows a considerably uneven distribution of the values that are apparently randomly dispersed around the average (average 30.448, variance 93.624). This is especially true for the schistose intercalations, while in the « Cenerigneisses » the ratio is different mainly in samples very rich in hematite; the influence of graphite on the values obtained for ferrous iron could not have been evaluated because this mineral, though present in every sample, was not quantitatively determined.

While the R_{ox} in « Cenerigneisses » is relatively constant, in the Val Strona paragneisses, studied by Sighinolfi (1968), this ratio shows strong variation: this is possibly due to a higher mobility of oxygen

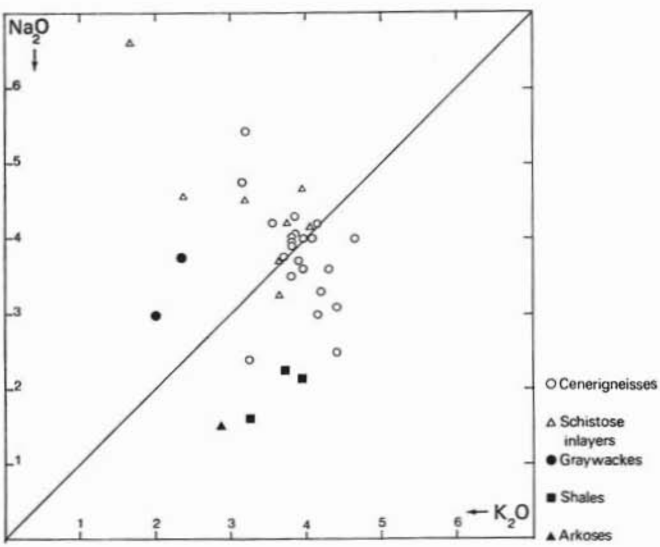

Fig. 4. — For explanation see text.

in the gaseous phase present in « Cenerigneisses » during anatexis than in the solid state process which determined the recrystallization of the paragneisses; this mobility could have diminished the difference between the layers with different R_{ox}.

The calc-silicate xenoliths, and the alluminium excess represented by garnet and kyanite prove without any doubt that the parent material was a sedimentary rock. To establish the nature of this rock on Na_2O-K_2O diagram the average values of graywackes, arkoses, slates and shales, given by Pettijohn and Bastrom (fig. 4) have been plotted. The representative points of « Cenerigneisses » fall in a intermediate position between shales and graywackes. The K content is that of shales, while the Na content is that of graywackes. Owing to the presence of calc-silicate xenoliths and considering the chemical composition, we suggest that « Cenerigneisses » originate from a sedimentary series with shales and graywackes and minor marl intercalations. The homogeneous chemical characters could have been due to metasomathism or anatexis.

Conclusions.

The southernmost part of the main horizon is formed of alternating schistose « Cenerigneisses », paragneisses and fine grained gneisses, that were interpreted (Boriani 1968) as a « transition zone », due to a selective anatexis in the lower temperature part of the metamorphic series.

The present study shows that there is no difference between schistose and non-schistose « Cenerigneisses », therefore the textural variety is only due to a different distribution of deformation; it is thus probable that the intercalations of paragneisses represent very tight folds of enclosing rocks penetrating into the « Cenerigneisses » body.

Because of the chemical homogeneity of these rocks, it seems reasonable to reject Reinard's hypothesis of a simple metamorphism of a sedimentary series, in fact such an interpretation does not explain the surprising homogeneity of the chemical composition of these rocks; Bächlin's suggestion that « Cenerigneisses » are to be considered as « Mischgneise » seems to be conformable to the new data, but it must be emphasized that the process which gives a more complete account of the characters observed is the differential anatexis of an originally inhomogeneous sedimentary series.

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