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Original Scientific Paper

Stratigraphy and Geochemical Characterization of the Middle Triassic - Carnian Sequence of the Lumiei Valley (Carnia, Northeastern Italy)

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Abstract

Stratigraphy of carbonate and terrigenous beds of the Anisian, Ladinian and Carnian of the Lumiei Valley (Middle-Western sector of Carnia, NE Italy) is updated and referred to the new chronological scale of Triassic.

Western Carnian Alps were emerged in Early Anisian time. The sea transgressed southward and the region was covered by a thick sequence of lagoonal, clastic, and pelagic sediments. The sequence is thicker in this area, where a system of synsedimentary faults increased the subsidence.

Tectonic activity increased during Middle(?) Anisian; this area turned into a topographic and structural high, divided by synsedimentary faults from neighbouring open-marine areas that received large amounts of terrigenous sediments.

The latest Anisian and the Ladinian are characterized by a general progradation of the platform facies. Basin areas with pelagic and volcanic sediments were mostly developed in this area and towards the Carnian-Julian Alps.

In the Late Ladinian a local resuming of volcanism is present in the transgression marked by the Acquatona Formation. The topmost part of the Ladinian is characterized by the general and wide diffusion of the inner platform, mostly with peritidal facies. At the Ladinian-Carnian boundary, tensional tectonics caused the breaking up of the Schlern platform and increased the subsidence.

In the Early-Middle Carnian, this area is dominated by a marine transgression with marly limestone, pelagic, and terrigenous sediments.

Moreover, major, minor and trace elements were determined. Statistical multivariate analysis methods were applied to experimental geochemical data to study the stratigraphic sequence. The purpose of this paper was to verify the capacity of these methods to describe the different lithologies of the sequence through its geochemical analysis.

A multivariate statistical analysis based on geochemical parameters identifies distinct groups of sediments corresponding to lithological intervals of the examined sequence.

In this way a good correspondence between geochemical groups and the lithologies was established.

1. INTRODUCTION

Features going from the Upper Permian to the Middle Carnian outcrop in the area which orographically belong to the Central-western Carnian Alps (Fig. 1) (PISA, 1974a). Due to the presence of tectonic events, this sequence is neither complete nor regular.

The studied area was chosen as it is the only place in the whole of Carnia where a continuous sequence outcrops, going from the Lower Anisian to the Middle Carnian, and without tectonic elision.

The aim of this paper is to provide data on geological features of this area, to define a more detailed local stratigraphic sequence different from the one already described in the literature (SELLI, 1963; BRAGA et al., 1971; CANTELLI et al., 1971), and to define the relationships with coeval features of the surrounding areas studied by other authors (GORTANI & DESIO, 1927a, 1927b; ELMI & MONESI, 1967; CARLONI & GHIRETTI, 1970; PISA, 1972a, 1972b, 1974a, 1974b; ASSERETO & PISA, 1973; METZELTIN, 1973; MARINELLI, 1980; PISA et al., 1980; FARABEGOLI & LEVANTI, 1982; FRASCARI, 1982; CARULLI et al., 1982, 1987).

The author to whom most reference is made is PISA, who has studied in detail and at different times (1972a, 1972b, 1974a, 1974b; CASTELLARIN & PISA, 1973; PISA et al., 1979) areas which are very close to those described in this paper. The units found during the surveys were named by completely adopting the terminology and chronology referred to in his quoted works, thus diverging at times from what was described in SELLI (1963), BRAGA et al. (1971) and CANTELLI et al. (1971); both from stratigraphical and from lithological and structural point of view.

Furthermore, for the first time in this sector, an attempt has been made to characterize the above-mentioned sequences from a geochemical point of view (BARBER, 1974) through the study of the elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Zn, Cu, Sr) and CO_2 which were deemed significant for this preliminary stage of the survey.

2. STRATIGRAPHIC SEQUENCE

2.1. STRATIFIED DOLOMITE ROCKS (LOWER ANISIAN)

PISA (1972a; 1974b) gives this name to the bottom unit of the sampled sequence. In the examined area, this

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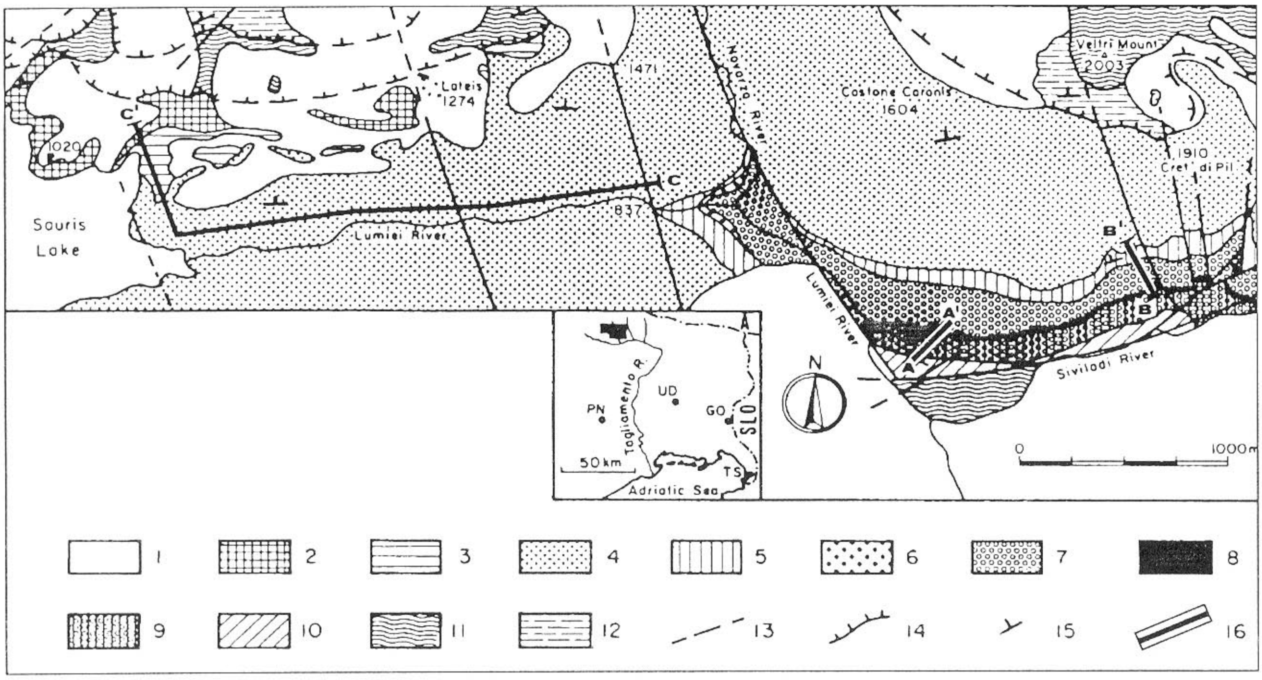

Fig. 1 - Geological Map. 1- Quaternary Deposits; 2- Violet Sandstones (Middle Carnian); 3- Brown Stratified Limestones (Middle Carnian); 4- Light, Massive and Stratified Dolomites and Dolomitic Limestones (Upper Ladinian - Middle Carnian?); 5- Livinallongo Formation (Buchenstein l.s.) (Upper Ladinian); 6- Ammonitic Red Limestones (Upper Ladinian, basal part); 7- Dolomitic Limestones on Tiarfin Mount (Upper Anisian - Lower Ladinian, upper part); 8- Anisian Basin Unit (Middle Anisian - Upper Anisian, part); 9- Serla Dolomite Rock (Lower - Middle Anisian, upper part); 10- Stratified Dolomite Rocks (Lower Anisian); 11- Werfen Formation (Scythian); 12- Bellerophon Formation (Permian); 13- Faults; 14- Overthrusts; 15- Attitude; 16- Geological Sections.

unit consists of macrocrystalline whitish dolomite rocks, which are clearly stratified in levels of 5-20 cm, and which at times can reach 20-40 cm.

The thickness of the formation was not measured because of the tectonic elision.

Analyses of thin sections revealed that the rock was made of microsparites and sparites (FOLK, 1959, 1974), with considerable dolomitic marks (dolomicrosparites and dolosparites) and fossil remains which had been obliterated by dolomitization.

The depositional environment of the unit apparently consisted of flat, shallow, extended beds (BOSELLINI, 1965) typical of the tidal flat; more specifically, according to ASSERETO et al. (1977) these should be external lagoon deposits.

The rock's are mostly consisted of dolomite, according to PISA (1972a; 1972b; 1974b) and ASSERETO et al. (1977).

2.2. SERLA DOLOMITE ROCK (LOWER-MIDDLE ANISIAN, UPPER PART)

This is the name given to the carbonate unit between the "Stratified Dolomite Rocks" and the "Anisian Basin Unit" by PISA (1974a, b).

In the examined area, the formation consists of banks or, subordinately, of 30-40 cm dark or light grey strata, with continuous exposure in the area of the Siviladi River, where a 102 m width was measured.

An analysis of thin sections revealed that the rocks consist mainly of microsparites or sparites, with intraclasts (intramicrosparite), organic fractions (biomicrosparite and biosparite), coated grains and, at times, some pellets.

The depositional environment seems to have been foreshore and backshore, as shown by the frequent occurrences of cavities of phreatic-vadose origin.

Chemical analyses showed that the formation has a calcitic composition in its bottom part, and tends to acquire dolomitic characteristics near the contact with the underlying "Stratified Dolomite Rocks". Along the sampled sequence, the central body is characterized by the presence of a consistent dolomitic belt about 25-35 m thick. Conversely, the top is typically calcareous.

Despite the presence of these dolomitic episodes, the composition partially differs from what is stated in the literature. PISA (1972a, b, 1974b) describes chemical compositions having a dolomite percentage greater than 90%; he also describes lithotypes such as whitish or nut-brown grey crystalline and saccharoid dolomite rocks, and light grey calcareous crystalline dolomite rocks. This apparent inconsistency may be due to the depositional environment fairly articulated. This kind of environment can generate different transformations in the diagenetic post-depositional stage.

The lower boundary with the "Stratified Dolomite Rocks" is not very clear; indeed, the fairly gradual passage suggests a possible facies heteropy between the two units. This hypothesis has already been suggested by PISA (1972a).

2.3. ANISIAN BASIN UNIT (MIDDLE ANISIAN - UPPER ANISIAN, PART)

The formation is the "Multi-coloured limestones and marls" and the "Bivera Mount Schichten" as described by PISA (1972a, b). He subsequently subdivided it (1974a, b) as follows:

a) the "Dont limestones", corresponding to the basal part of the sequence and ascribable to the Middle-Upper Anisian;

b) the "Bivera Mount Formation", developing through virtually all the Upper Anisian.

Along the examined sequence, from bottom to top, it is possible to find:

- alternating red and yellowish marls with rounded calcareous marly inclusions, the diameters of which can be up to 8 cm, followed by fine-grained dolomitic-calcareous marls having a yellowish-bluish-greenish colour, and a total width of approximately 8 cm;
- black marls and argillaceous grey and yellow grey marls of thickness 8 m, with continuous small layers 3-5 cm thick in their basal part, and frequent rounded marly-calcareous nodules the diameter of which can be up to 10 cm in the upper part of the sequence.

These lithologies represent the above-mentioned formations with a clear predominance of those which can be ascribed to the Bivera Mount Formation.

Thin sections reveals that the rocks consist of micrites, microsparites, sparites with bioclasts, frequent ferrous coatings, and often show an considerable terrigenous input (biotite, muscovite and quartz) which at times generated siltites and carbonate concrete.

The depositional environment of the unit is as described by other authors (PISA, 1972a, b, 1974b; ASSERETO et al., 1977): open sea evolving, in the upper part of the formation, to shallower sea probably with conditions of greater energy suitable for the gradual development of a carbonate platform environment.

2.4. DOLOMITIC LIMESTONES OF MOUNT TIARFIN (UPPER ANISIAN - LOWER LADINIAN, UPPER PART)

This name is given to the carbonate platform overlying the Anisian basinal formations in central-western Carnia (PISA, 1972b, 1974a, b).

In the studied area, the formation can be found in large grey or light brown-coloured massive banks, mostly lacking a clear stratification.

Thin sections reveals that the rock consists of micrites, microsparites, and sparites, with a fairly well developed bioclastic fraction and the presence of lumps, pellets, intraclasts (biomicrites, biomicrosparites, intramicrosparites) and rare terrigenous input.

The environment is a foreshore-backshore carbonate platform, with frequent phreatic-vadose dissolution and, at times, geopetal fillings.

Chemical analyses showed that the composition is typically calcareous, unlike that found by PISA (1972a, 1974b) and by ASSERETO et al. (1977) in the areas they examined. As in the case of the previous Anisian platform, this apparent inconsistency might be due to the fact that, although a single depositional basin, it was highly articulated and differentiated internally. A further confirmation of this comes from the thickness of the formation, which is approximately 190 m, that is to say, much smaller than the formation found closeby on the north-western slopes of Tinisa Mount, where the unit can be up to about 400 m thick (ALBORGHETTI, 1975). PISA (1974b) describes similar features, justifying them by not a completely regular trend of the formation itself.

The upper boundary with the "Ammonitic Red Limestones" occurs both directly and through a breccia dolomitic horizon of a rather limited thickness.

Elsewhere, in the central Carnian Alps, given not always a continuous distribution of the "Dont limestones" and of the "Bivera Mount Formation" at the bottom, and of the "Ammonitic Red Limestones" at the top, the lower and the upper contacts of the "Tiarfin Mount Dolomitic Limestones" occur with the "Serla Dolomite Rocks" and with the "Livinallongo Formation", respectively.

2.5. AMMONITIC RED LIMESTONES (UPPER LADINIAN, BASAL PART)

This unit corresponds to the "Ammonitic Red Limestones" ("Clapsavon limestones") (PISA, 1974b), and to the "Clapsavonkalke" described by German scientists and by PISA (1974a).

The typical facies of red or pink-coloured limestones is replaced in this area by grey, at times dolomitic, fine or very fine-grained limestones having a stratification of about 15-50 cm and frequent nodular junctions.

The hard-ground type siliceous or ferrous-siliceous crusts of a brown-red colour frequently appearing at the tops of the layers in nearby outcrops are absent in this zone.

A study of thin sections revealed that this rock consists of micrite and intraclasts and has an organic fraction consisting of pelagic pelecypods, almost completely recrystallized radiolaria, pellets and scant terrigenous supplies (small angular quartz grains). Chemical analyses reveal a typically calcareous-dolomitic composition.

The depositional environment must have been a protected platform zone where the accumulation of calcareous mud due to currents was possible.

Heteropic facies relationships with the underlying Anisian-Ladinian platform are not to be excluded.

2.6. LIVINALLONGO FORMATION (BUCHENSTEIN l.s.) (UPPER LADINIAN)

This is the name given to all the various lithologies included between the two carbonate platforms of the

"Tiarfin Mount Dolomitic Limestones" (or the "Calcari rossi ad Ammoniti", if present) below, and the "Light, Massive and Stratified Dolomites and Dolomitic Limestones" above. Therefore, the features that are considered here should correspond to the sequence which PISA (1974b) indicated as the "Livinallongo Formation" (Buchenstein), "Volcanites", "Wengen Formation" and "San Cassiano Formation".

It is very difficult to correctly define this interval, especially with regard to the various volcanic-clastic lithologies ("pietra verde"), given the considerable vertical and lateral variability of these sequences. Indeed, in Carnia and Cadore, the "pietra verde" was found both in the Anisian and in the Ladinian (VIEL, 1979), and therefore cannot be considered a lithostratigraphic marker. Nevertheless, on the basis of the lithological sequence only, there is a tendency to identify, in the lower part of the studied sequence, features which can be attributed to the "Livinallongo Formation s.s." described by CASTELLARIN & PISA (1973), PISA (1974b), VIEL (1979), and JADOUL & NICORA (1986), and, in the upper part, lithotypes which can be attributed to the "Acquatona Formation" described by VIEL (1979) and by JADOUL & NICORA (1986).

This general distinction does not allow clear identifications of the intraformational structure, given the continuous alternations and gradual changes over great widths. At an informal level, however, this sequence can be divided in two parts: a 64 m thick lower part where, despite the presence of a few calcareous features (sample 38), the prevailing lithology is marley-clayey-silty-arenaceous, and a 105 m thick upper part, where the calcareous component prevails. Specifically, where sampling was possible, the following lithotypes were found from bottom to top:

- compact lutite "pietra verde", in 5-15 cm strata, with rare, small (3-4 cm) limestone strata of a nodular tendency, having an overall width of about 60 m;
- black, sometimes yellow-greenish, marly limestones, in 3 to 8 cm strata, alternating with "pietra verde" strata towards the lower part; the overall thickness is 4 m;
- "breccia" horizon (outcropping for about 1 m, but hidden towards the upper part by a 35 m covering), with white and greenish carbonate clasts, of which the smaller are rounded (2-3 cm) and the larger are flattened (up to 20 cm), in a carbonate and volcanoclastic concrete;
- blackish calcilutites in 7 to 30 cm strata alternating with less frequent fine 15-20 cm strata of "pietra verde", containing blackish calcareous levels; towards the upper part, flintstone lists and nodules, with green marly millimetric interstrata; the overall thickness is 10.2 m; at 7 m from the base, the last lutite "green rock" of 20 cm thickness appears;
- after 20 cm of layered green clayey marls, 11.6 m of grey or blackish limestones, at times with red veins, in 5 (more frequently) to 40 cm strata, with thin black flinstone levels towards the base, and reddish clayey marl interstrata towards the top;
- blackish limestones, in 6 to 15 cm strata, with an overall thickness of 37 m;
- 4.5 m thick massive limestones;
- limestones and calcarenites in 20-30 cm strata totalling 6 metres underlying the massive platform, which can be clearly attributed to the "Light, Massive and Stratified Dolomites and Dolomitic Limestones".

2.7. LIGHT, MASSIVE AND STRATIFIED DOLOMITES AND DOLOMITIC LIMESTONES (UPPER LADINIAN - MIDDLE CARNIAN?)

This completely informal name was chosen by PISA (1972a and 1974b) to define the carbonate body included between the "Livinallongo l.s. Formation" below, and the "Brown Stratified Limestones" above.

The unit corresponds to the "Schlern Dolomite" (PISA, 1972b), and to the "Cassian dolomite rock" described by PISA et al. (1980), MARINELLI (1980) and CARULLI et al. (1987).

From a macroscopic point of view, the rock is grey-light brown or grey, compact and with no particularly evident stratification marks. Indeed, in these areas, the formation loses in its upper part the marked stratification which was observed closeby in the Sesilis-Nauleni Mounts (ALBORGHETTI, 1975) and also noted by PISA (1972a, b, 1974b) and ASSERETO et al. (1977).

An analysis of thin sections reveals that the rock consists mainly of microsparites, sparites and micrites, with considerable amount of fossil remains (biomicrites and biomicrosparites), intraclasts, authigenic quartz, a few coated grains, pellets and/or lumps.

The deposition environment is probably the same as the other carbonate platforms, that is to say, a foreshore-backshore environment, as evidenced by frequent phreatic-vadose cavities.

From a chemical point of view, notwithstanding the name given to the unit, the calcareous character of the rock is evident, with only a few dolomite rock features linked mostly with the presence of possible paleokarstic pockets which could indicate short emersions of the platform. Even in this case, local differentiation of the environment is believed to have been the cause of the variation in the rock's mineral features, which were elsewhere described as dolomitic (PISA, 1972a, 1974b). The outcrops of the examined unit, about 410 m thick, are widespread in this area.

2.8. BROWN STRATIFIED LIMESTONES (MIDDLE CARNIAN)

These are blackish or dark-grey limestones (PISA, 1972a, 1974b), fetid when struck, extremely rich in lamellibranchs and gastropods, in strata with thicknesses varying from 10-40 cm up to 80-100 cm, with undulating joints and some marly interbedded black layers up to 15 or 20 cm thick (minimum thickness 4- 5 cm).

Thin sections reveals that they are composed of micrites and microsparites, with a considerable percentage of organic remains (biomicrites), represented mainly by lamellibranchs, gastropods and ostracods, together with intraclasts and a terrigenous supply which, at times, can be abundant.

This lithology indicates a gradually drowning carbonate platform, due to an increasing input of terrigenous components, leading to a neritic environment.

In the studied area, the formation reaches a thickness of 60 m.

2.9. VIOLET SANDSTONES (MIDDLE CARNIAN)

These are mostly reddish and grey quartzose sandstones (PISA, 1972a) in strata or banks, which can be irregularly intercalated with grey or blackish limestones, or with reddish or reddish- greyish silts.

They have a varying grain-size (mostly coarse) with reddish flint inclusions. The thickness of the individual strata varies between 5 cm and 4 m. At times, rather clear-cut cross laminations are evident.

As they degrade easily, they can be found in many outcrops with a typical grey-brownish colour owing to weathering processes which can be very marked.

An analysis of thin sections from the basal part of the unit reveal that they are quartzose-feldspathic sandstones having an extremely variable grain-size and both a carbonate and siliceous cement; volcanic-origin fragments are present, together with other fragments probably of philladic-sericitic origin.

The top has not been considered since the unit is tectonically truncated by the "Sauris line" (PISA, 1972a).

2.10. QUATERNARY DEPOSITS

In the geological map of Fig. 1, the Quaternary deposits are shown generally for ease of representation, but they are well developed. They are basically "Cemented breccias and conglomerates", "Morainic deposits" and "Detritus".

3. TECTONICS

The disjunction elements found in the area and shown in Fig. 1 are determined by overthrusts and folds.

The former are the most important tectonic disturbances in the examined area. Among the most conspicuous ones is the one known as the "Sauris line", as can clearly be seen in the geological map (Fig. 1) (SELLI, 1963; PISA, 1974a; CARULLI et al., 1982). This is the most important south-verging tectonic feature in the whole of the Carnian sector. It follows a general E-W direction for about 30 km from Tolmezzo to the Mauria Pass and is interrupted by various transverse faults.

This tectonic disturbance usually pushes the Scythian and/or Permian over the Carnian with a N-S movement.

In this sector, the "Sauris line" comes in contact with another tectonic line, substituting the "Scalotta River - Rucke Mount - Olbe Mount line" (PISA, 1974a), which has an analogous trend, and results in the Permian terrains (Bellerophon Formation) overthrusting the Scythian represented by the "Werfen Formation". This tectonic pattern can be clearly identified throughout the northern part of the studied area as far as the "Forca di Frameiben" (Lateis) where, probably due to the presence of a fault, the northern overthrust is abruptly dislocated and does not seem to proceed eastwards; the southern overthrust, that is to say the "Sauris line", continues and is clearly visible on the left bank of the Novarza River as far as the south-eastern slopes of Veltri Mount, where it links Permian beds (calcareous member of the "Bellerophon Formation") with Ladinian-Carnian carbonate rocks.

In this sector, overthrusts come with two groups of faults: one with an almost E-W direction, and the other with an average N-S direction.

From a paleogeographic and paleostructural point of view, this area belongs to the "Cadore-Carnia basin" (DE ZANCHE, 1990), which, during the Triassic, was the site of consistent subsidence and sedimentation owing to abundant supplies deriving from the heights surrounding it, and to reactivations of the existing synsedimentary stretching tectonics (BOSELLINI et al., 1982; DOGLIONI, 1984). Towards the end of the Triassic (Carnian-Norian), the beginning of compressive tectonics led the Permian-Scythian terrains to overthrust Carnian terrains ("Sauris line" and "Scalotta River - Rucke Mount - Olbe Mount line"). This stage of shortening subsequently generated E-W (NE-SW) and NW-SE vertical fault systems, with rarely pronounced throws, probably indicating the partial reactivation of old synsedimentary systems.

In this tectonic framework, great importance is attached in the studied area to the Siviladi River E-W (NE-SW) fault, which causes considerable dislocation, and elements of the "Werfen Formation" touch the Anisian carbonate rocks.

Similarly, the NW-SE fault on which the lower reaches of Novarza River and part of the Lumiei River flow is responsible for the large dislocation which brings into contact the "Tiarfin Mount Dolomitic Limestones" and the Ladinian-Carnian sequences.

In the Siviladi River area also, faults having a N-S direction are present. They are clearly visible on the southern slopes of the "Cret di Pil", but they seem of little importance.

4. DESCRIPTION OF SEQUENCES

Given the clear local stratigraphic situation, as described in the introduction, the study of a continuous sequence from the Lower Anisian to the Middle Carnian was possible. Owing to the sometimes difficult accessibility of the site, the area was studied along three sections (A-A', B-B' and C-C'), as shown in Fig.1, and located respectively as follows :

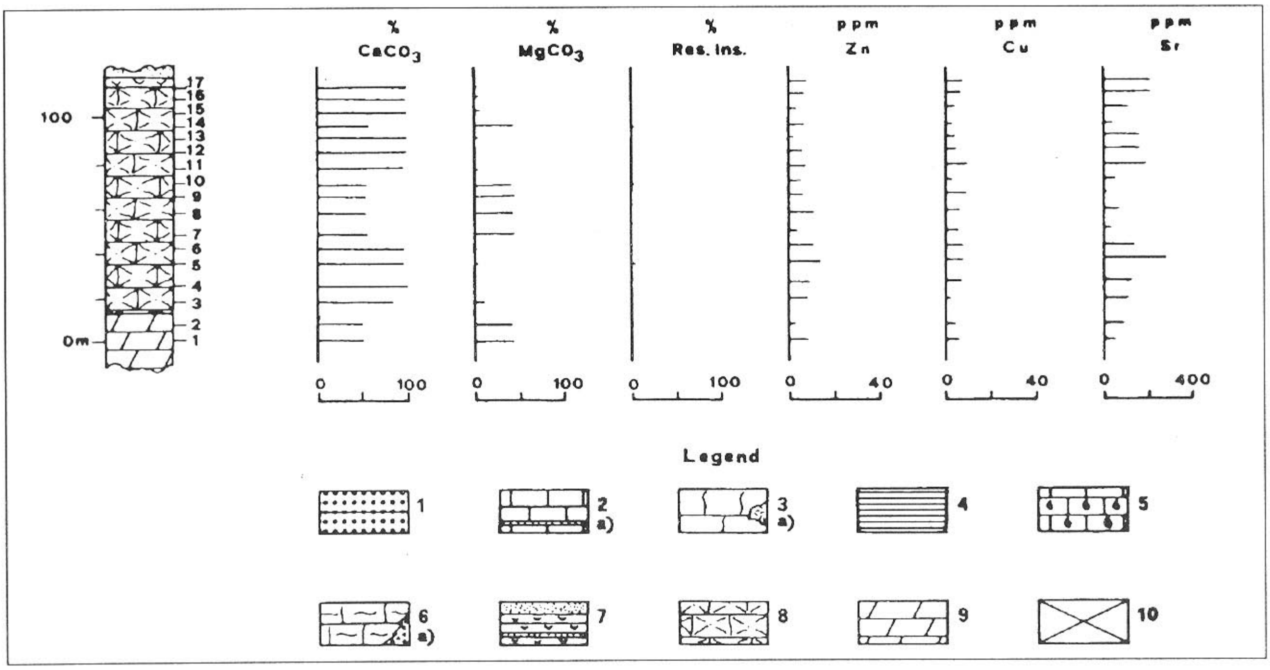

Fig. 2 - Siviladi Valley Section (A-A') and geochemical characteristics. 1- Violet Sandstones (Middle Carnian); 2- Brown Stratified Limestones, (a) marly beddings (Middle Carnian); 3- Light, Massive and Stratified Dolomites and Dolomitic Limestones, (a) paleokarst (Upper Ladinian - Middle Carnian?); 4- Livinallongo Formation (Buchenstein l.s.) (Upper Ladinian); 5- Ammonitic Red Limestones (Upper Ladinian, basal part); 6- Dolomitic Limestones on Tiarfin Mount, (a) dolomitic breccias (Upper Anisian - Lower Ladinian, upper part); 7- Anisian Basin Unit (Middle Anisian - Upper Anisian, part); 8- Serla Dolomite Rock (Lower - Middle Anisian, upper part); 9- Stratified Dolomite Rocks (Lower Anisian); 10- Covered Section.

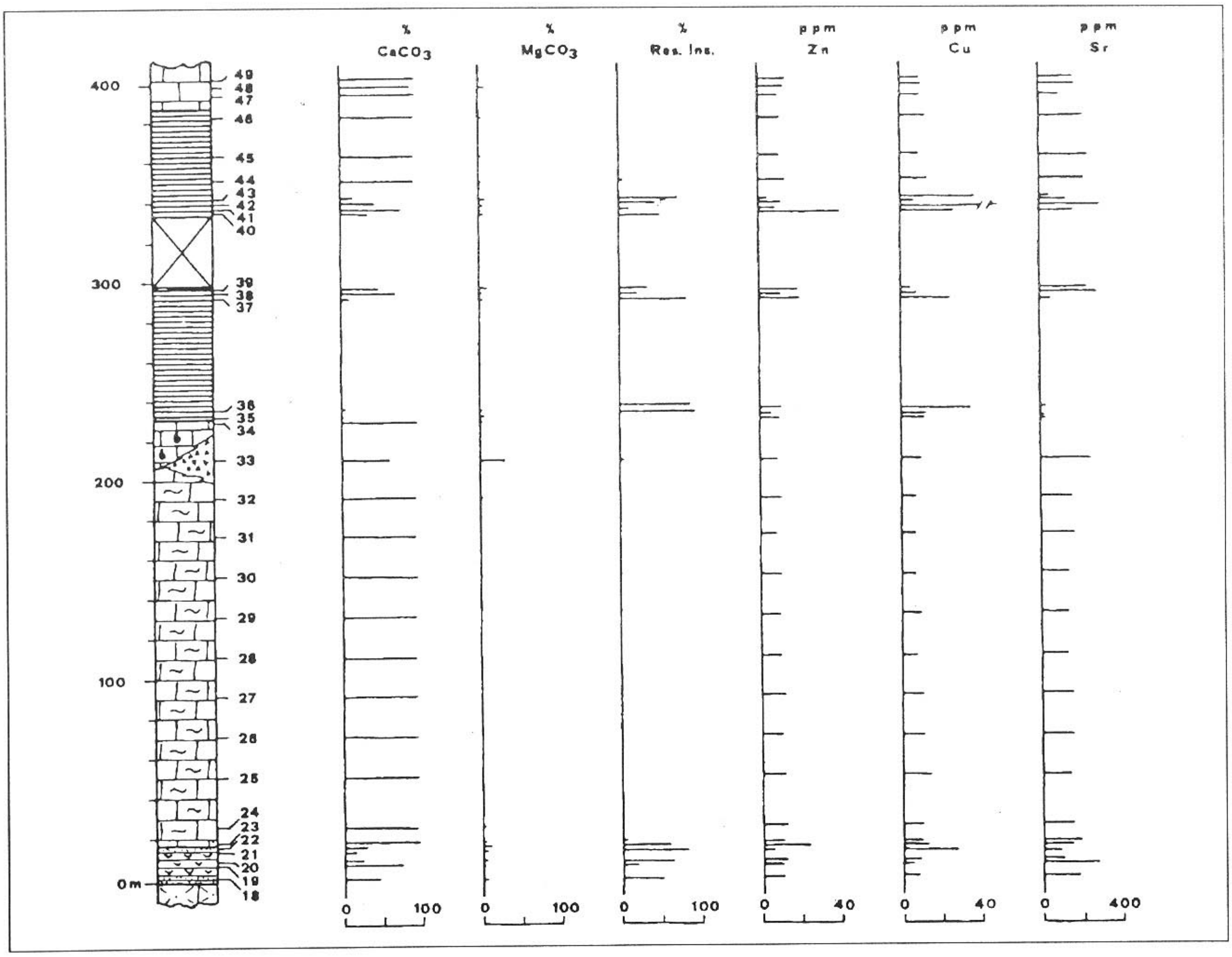

Fig. 3 - Cret di Pil Section (B-B') and geochemical characteristics. See Legend of the Fig. 2.

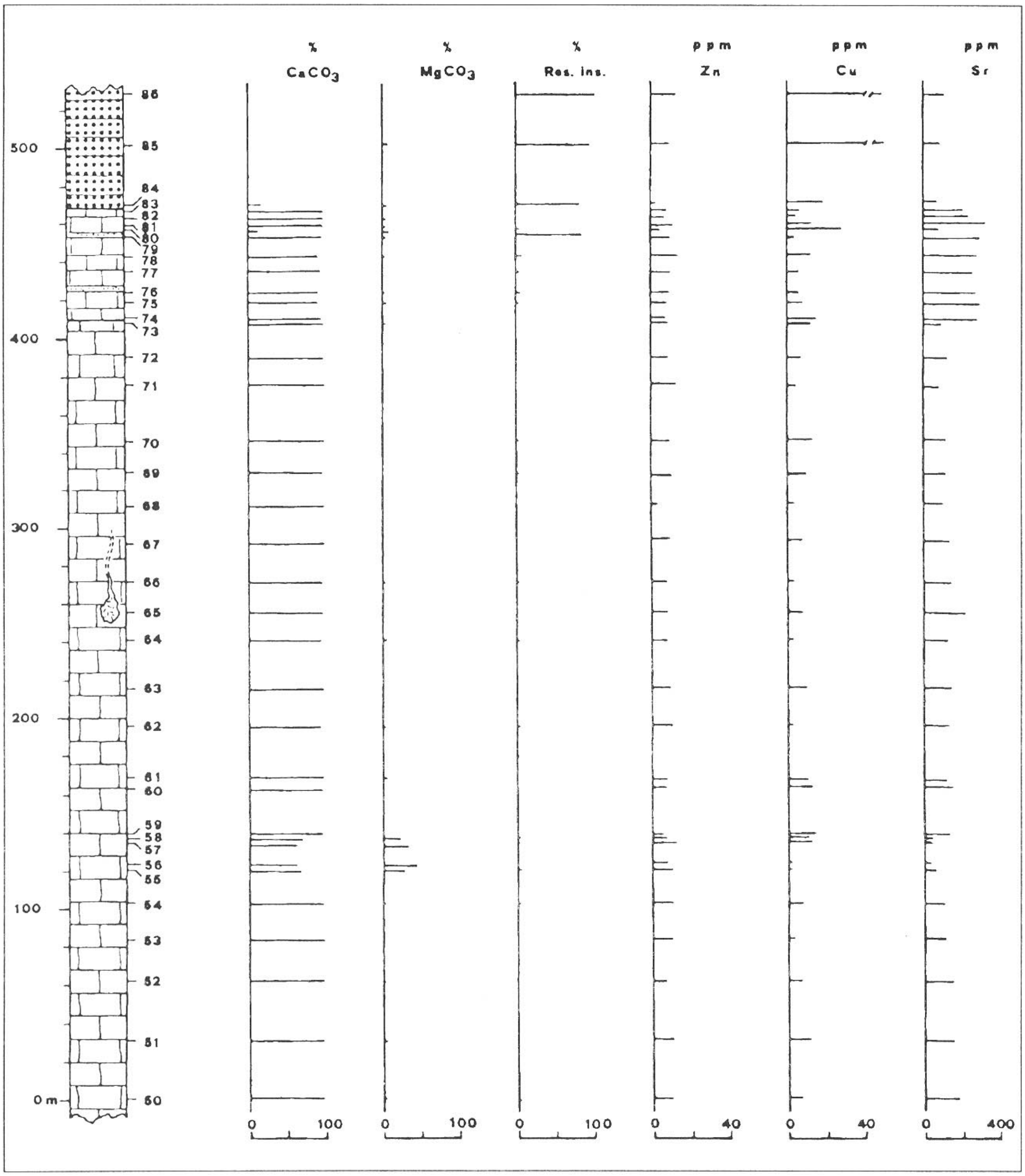

Fig. 4 - Lumiei Valley Section (C-C') and geochemical characteristics. See Legend of the Fig. 2.

1) A-A' - Siviladi valley section (Fig. 2) - A 839 m valley on the path going from Oltris village northwards towards "Costone Coronis", beyond the Siviladi River, which is the left tributary of the Lumiei River; this area includes the roof of the "Stratified Dolomite Rocks" (Lower Anisian) and the entire carbonate body of the "Serla Dolomite Rock" shelf, including, therefore, the whole of the Middle Anisian;

2) B-B' - "Cret di Pil" section (Fig. 3) - On the southern slopes of this mountain, on the right bank of the Siviladi River; this section includes, from the top downwards, the "Anisian Basin Unit", the "Dolomite Carbonates of Tiarfin Mount", the "Ammonitic Red Limestones", the "Livinallongo l. s. Formation", and the basal part of the "Light, Massive and Stratified Dolomites and Dolomitic Limestones", covering an interval going from the final part of the Middle Anisian nearly to the top of the Upper Ladinian;

3) C-C' - Lumiei valley section (Fig. 4) - On the stretch going from the 837 m high bridge over the Lumiei River to the village of Lateis; this section includes, from bottom to top, "Light, Massive and

Stratified Dolomites and Dolomitic Limestones", "Brown Stratified Limestones" and the basal part of "Violet Sandstones", thus covering the interval that can be referred to the top of the Upper Ladinian as far as the base of the Middle Carnian.

5. SAMPLE PROCESSING AND CHEMICAL ANALYSES

For the purpose of the research, a fairly dense sampling was deemed necessary, even where the prevailing facies were constant (in this case, the average distance between two successive samples did not exceed 10-15 m), as well as an accurate measurement of the sequence with a tape measure.

Several bedrock fragments (10-15) totalling about 300-400 g were taken from each sampling point for geochemical analyses, and a larger whole sample for preparing thin sections. Fragments were gathered mostly within a 2-3 square-metre outcrop area in order to keep the rocks representative of the sampling locality.

Each sample was cleaned of altered parts, ground and reduced to dust; a part of it was used to determine CO_2 with a Dietrich-Fruhling calcimeter. The other elements were determined by X-ray fluorescence spectrophotometry.

The concentrations of the determined elements are referred to in Tab. 1 and in Figs. 2, 3 and 4, while a sample location map is given in the Tab. 3.

6. STATISTICAL ELABORATION

In studying the stratigraphic sequence, statistical multivariate analysis methods were applied to the experimental geochemical data.

The contents of SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, CO_2, Sr, Zn and Cu, for the 86 samples were elaborated by means of Q-Mode factor analysis (KLOVAN & MIESCH, 1976) and of cluster analysis (SPSS-PC package).

The purpose was to verify this method's capacity to completely describe the sequence with regard to the different lithologies and to evidence the analytical power of the statistical procesing.

Indeed, the aim of the factor analysis is to describe variations in a group of data using the smallest possible number of factors, each of which consists of one or more variables, so as to obtain a concise but all the same significant representation of the variability itself (DAVIS, 1986; ROCK, 1988).

The Q-Mode factor analysis (JÖRESKOG et al., 1976) allowed determination of the composition of these factors as a function of the geochemical species.

Having identified the sample factor loadings for each factor, the samples were grouped according to these characteristics to obtain groups of samples of the same geochemical definition.

In order to get to this point, a cluster analysis was carried out on the same factor loadings of the most significant factors identified by the Q-Mode analysis.

The groups which were obtained in this way allowed a correlation of the lithological and geochemical features of the sequence described.

7. RESULTS AND DISCUSSION

An assessment of the numerical data regarding the contents of the various oxides shows that, among the major elements, SiO_2 has the highest percentages, followed by CaO, the values of which are much lower, but yet higher than those of the remaining oxides. Then follow MgO, Al_2O_3, K_2O, Fe_2O_3 and Na_2O.

Among the minor elements, TiO_2 is the most abundant, followed by MnO and P_2O_5.

Given the typically carbonate nature of the sequence, data on CO_2 are characterized by large fluctuations and reach a maximum level of 47.87% in the carbonate types, and a minimum level of 0.52% in rocks having a prevailing siliceous composition.

Concentrations of trace elements include Sr with the highest values, followed by Cu and Zn.

8. Q-MODE FACTOR ANALYSIS AND CLUSTER ANALYSIS

Application of Q-Mode factor analysis to the numerical values of the geochemical estimates identified 5 significant factors (Tab. 2).

Factor 1 (Fig. 5) is characterized by the following elements in decreasing order of importance: CaO, Sr, CO_2, Zn, and Cu.

CaO and CO_2 define the calcareous component; Sr and Zn are minor elements which are naturally linked to it (WEDEPOHL, 1969) whereas Cu is typical of the silicate phase. This first factor accounts for 52.63% of the total variance.

Fig. 5 shows the factor loadings of factor 1 for the samples of the stratigraphic sequence divided into the three sections.

Factor 2 (Fig. 6) clearly defines a silicate phase decribed by: SiO_2, Al_2O_3, K_2O, TiO_2, Fe_2O_3, and Na_2O. Factor 2 accounts for 20.45% of the total variance.

Factor 3 (Fig. 7) is characterized by MnO prevailing over Fe_2O_3. These two elements are still typical of a carbonate sedimentation environment. Factor 3 accounts for 11.50% of the total variance.

Factor 4 (Fig. 8) is characterized by MgO and thus belongs to a dolomitic phase. It accounts for 11.38% of the overall variance.

The presence of Na_2O (already seen in factor 2) as a significant element of **Factor 5** has not been clearly interpreted. It probably indicates anomalies in the carbon-

Sample	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	CO_2 %	Sr ppm	Zn ppm	Cu ppm
86	78.76	0.43	12.82	3.47	0.02	0.07	0.08	1.65	1.75	0.05	0.90	105.00	13.62	57.50
85	71.64	1.12	15.87	4.05	0.03	1.92	0.81	0.88	3.11	0.06	0.52	91.00	9.25	60.00
84	59.93	0.52	13.93	4.59	0.27	2.12	8.57	1.12	2.85	0.04	6.06	75.00	3.50	17.50
83	1.11	0.06	0.39	0.67	0.30	0.85	54.59	0.00	0.14	0.03	41.86	211.00	8.12	5.49
82	0.48	0.00	0.09	0.24	0.06	0.86	54.19	0.00	0.02	0.02	44.03	238.00	7.50	3.00
81	1.60	0.01	0.45	0.30	0.03	1.01	53.60	0.00	0.09	0.02	42.89	335.00	12.25	11.50
80	55.23	0.57	19.20	3.83	0.02	2.82	6.98	0.21	6.33	0.11	4.70	86.00	4.00	27.50
79	0.93	0.01	0.25	0.28	0.04	1.39	53.84	0.00	0.08	0.03	43.16	305.00	8.75	3.00
78	3.89	0.01	0.37	0.83	0.14	1.01	51.66	0.00	0.06	0.02	42.01	285.00	13.74	11.24
77	1.36	0.20	0.39	0.32	0.05	0.79	54.04	0.00	0.09	0.03	42.91	250.00	10.75	5.00
76	1.89	0.01	0.33	0.32	0.02	0.93	52.72	0.00	0.07	0.02	43.68	274.00	8.75	5.00
75	0.51	0.00	0.14	0.44	0.07	1.73	52.73	0.00	0.30	0.20	44.33	302.00	8.25	7.50
74	1.36	0.10	0.21	0.36	0.02	0.87	54.67	0.00	0.02	0.03	42.46	281.00	7.99	14.99
73	0.12	0.00	0.07	0.11	0.02	1.54	54.71	0.00	0.01	0.02	43.41	101.00	8.12	12.50
72	0.20	0.00	0.11	0.08	0.05	0.32	55.29	0.00	0.02	0.02	43.89	128.00	8.25	12.50
71	0.08	0.00	0.03	0.08	0.05	0.17	55.67	0.00	0.00	0.02	43.90	88.00	12.50	3.75
70	0.06	0.00	0.02	0.03	0.02	0.06	54.45	0.74	0.00	0.02	44.61	117.00	8.75	12.00
69	0.11	0.00	0.04	0.04	0.02	0.16	53.94	0.00	0.00	0.02	45.66	120.00	10.75	10.50
68	0.06	0.00	0.02	0.04	0.01	0.35	55.05	0.13	0.00	0.02	44.32	100.00	3.75	3.75
67	0.07	0.00	0.03	0.04	0.02	0.13	55.85	0.00	0.00	0.02	43.84	136.00	9.25	7.50
66	0.18	0.00	0.04	0.41	0.11	1.31	53.60	0.00	0.00	0.03	44.33	139.00	7.25	2.50
65	0.11	0.00	0.05	0.18	0.05	0.85	54.48	0.00	0.01	0.02	44.26	205.00	8.17	7.47
64	0.33	0.01	0.16	0.44	0.10	1.34	53.33	0.00	0.04	0.03	44.23	132.00	7.50	2.50
63	0.07	0.00	0.03	0.17	0.06	0.54	55.74	0.00	0.00	0.02	43.36	143.00	8.74	9.49
62	0.04	0.00	0.02	0.85	0.18	1.47	52.75	0.00	0.00	0.02	44.67	139.00	10.00	2.50
61	0.06	0.00	0.03	0.84	0.16	1.70	53.64	0.00	0.00	0.02	43.56	109.00	8.00	10.00
60	0.05	0.00	0.02	0.49	0.12	0.83	54.90	0.00	0.00	0.02	43.58	144.00	6.50	12.00
59	0.03	0.00	0.01	0.20	0.06	0.74	54.71	0.21	0.00	0.02	44.01	128.00	5.50	15.00
58	0.07	0.00	0.04	2.81	0.38	10.70	41.18	0.00	0.00	0.03	44.78	33.00	6.25	11.50
57	0.15	0.00	0.08	2.52	0.39	15.97	35.51	0.00	0.01	0.04	45.33	39.00	11.75	12.00
56	0.14	0.00	0.07	0.20	0.02	21.45	31.55	0.00	0.01	0.02	46.53	15.00	7.25	2.50
55	0.48	0.00	0.09	1.78	0.29	12.74	38.62	0.16	0.01	0.04	45.78	39.00	9.25	2.50
54	0.10	0.00	0.04	0.72	0.17	1.33	53.48	0.20	0.01	0.03	43.91	105.00	8.75	7.50
53	0.09	0.00	0.04	0.01	0.04	0.39	55.07	0.00	0.01	0.02	44.33	110.00	8.75	3.75
52	0.07	0.00	0.04	0.08	0.02	0.94	55.01	0.00	0.00	0.03	43.80	151.00	8.12	6.50
51	0.12	0.00	0.06	0.07	0.01	1.23	54.53	0.00	0.01	0.03	43.94	148.00	9.25	11.50
50	0.90	0.01	0.22	0.24	0.08	0.71	53.81	0.00	0.09	0.03	43.11	171.00	8.75	7.47
49	0.45	0.01	0.19	0.07	0.01	0.92	54.81	0.00	0.05	0.03	43.47	166.00	12.50	9.50
48	0.63	0.01	0.09	0.09	0.02	2.90	52.75	0.00	0.02	0.02	43.47	173.00	12.22	11.50
47	0.09	0.00	0.03	0.05	0.02	0.39	55.72	0.00	0.00	0.03	43.68	99.00	8.75	9.25
46	0.33	0.00	0.07	0.09	0.01	1.12	54.21	0.00	0.02	0.03	44.12	207.00	10.00	12.50
45	2.50	0.00	0.06	0.13	0.01	0.83	53.83	0.00	0.01	0.02	42.60	239.00	9.00	9.50
44	2.25	0.04	0.65	0.47	0.04	0.99	53.35	0.00	0.20	0.04	41.97	219.00	11.75	13.50
43	52.92	0.35	18.57	3.21	0.02	3.80	8.59	0.05	6.49	0.07	5.94	53.00	2.50	37.50
42	46.43	0.16	2.97	1.54	0.09	1.75	25.74	0.25	0.77	0.06	20.24	133.00	9.00	7.50
41	14.68	0.06	1.15	1.14	0.10	0.81	46.03	0.10	0.24	0.05	35.65	297.00	7.50	95.00
40	39.39	0.98	11.54	3.69	0.06	2.38	21.99	1.03	4.07	0.13	14.74	163.00	41.00	27.00
39	30.42	0.53	9.18	7.46	0.20	3.87	28.38	1.25	0.97	0.15	17.61	229.00	18.00	4.80
38	25.22	0.09	1.68	1.77	0.22	1.35	39.56	0.09	0.25	0.06	29.70	283.00	8.70	7.00
37	65.92	0.58	12.54	4.12	0.04	2.50	4.95	0.85	5.23	0.10	3.17	52.00	18.75	25.00
36	71.21	0.14	13.44	1.82	0.02	1.27	2.20	0.40	8.11	0.02	1.37	22.00	9.26	35.00
35	70.85	0.23	15.37	2.22	0.01	1.61	0.74	0.11	7.99	0.05	0.81	18.00	4.12	12.50
34	0.73	0.01	0.19	0.11	0.02	0.76	54.43	0.00	0.05	0.03	43.67	160.00	9.74	11.99
33	0.77	0.01	0.22	1.05	0.11	16.62	34.87	0.00	0.04	0.02	46.30	243.00	7.95	10.00
32	0.66	0.01	0.12	0.24	0.05	0.92	54.93	0.00	0.03	0.02	43.03	150.00	9.37	7.50
31	0.09	0.00	0.05	0.10	0.04	0.50	55.07	0.00	0.01	0.02	44.12	161.00	6.25	7.50
30	0.24	0.00	0.08	0.19	0.05	0.46	55.38	0.00	0.01	0.02	43.56	132.00	9.37	7.50
29	0.11	0.00	0.05	0.11	0.03	0.56	55.20	0.00	0.01	0.02	43.91	129.00	8.42	10.00
28	0.09	0.00	0.04	0.14	0.04	0.51	55.14	0.00	0.00	0.02	44.01	124.00	8.62	7.50
27	0.05	0.00	0.03	0.09	0.03	0.62	55.37	0.00	0.00	0.02	43.80	145.00	11.50	10.00
26	0.24	0.01	0.13	0.12	0.04	0.45	54.96	0.00	0.03	0.02	44.00	154.00	9.74	10.49
25	0.24	0.01	0.13	0.16	0.04	0.77	54.89	0.00	0.03	0.03	43.71	127.00	10.75	9.25
24	0.94	0.02	0.39	0.18	0.03	1.36	53.68	0.00	0.12	0.03	43.25	143.00	11.50	9.25
23	1.54	0.03	0.66	0.25	0.01	0.83	53.70	0.00	0.20	0.03	42.76	182.00	8.75	9.50
22	42.00	0.60	12.68	3.61	0.06	4.27	17.00	0.09	3.94	0.08	15.67	149.00	22.69	11.99
21	57.30	0.63	14.43	5.88	0.05	2.29	7.51	0.36	4.52	0.08	6.94	91.00	4.62	27.50
20	46.50	0.60	11.68	5.86	0.06	2.51	15.76	0.25	3.72	0.08	12.98	100.00	10.90	8.00
19	14.93	0.18	3.55	1.35	0.12	1.55	42.75	0.05	1.04	0.05	34.43	264.00	9.00	4.50
18	33.89	0.50	10.12	4.13	0.07	2.20	24.87	0.15	3.11	0.07	20.89	177.00	10.20	9.00
17	0.33	0.00	0.03	0.08	0.01	1.01	54.62	0.00	0.00	0.02	43.90	213.00	10.00	8.00
16	0.25	0.00	0.04	0.08	0.01	1.19	54.75	0.00	0.00	0.02	43.65	216.00	7.49	6.25
15	0.10	0.00	0.05	0.09	0.10	2.31	53.53	0.00	0.01	0.02	43.78	102.00	3.75	5.00
14	0.17	0.00	0.10	0.82	0.07	20.03	31.48	0.01	0.01	0.02	47.30	40.00	7.50	3.00
13	0.35	0.01	0.14	0.09	0.01	0.99	54.25	0.00	0.04	0.03	44.10	163.00	3.75	5.00
12	0.26	0.01	0.12	0.08	0.01	0.80	54.44	0.00	0.03	0.02	44.23	162.00	7.50	5.00
11	0.41	0.01	0.14	0.21	0.03	1.72	53.22	0.00	0.04	0.02	44.20	183.00	10.00	8.74
10	0.10	0.00	0.08	0.16	0.02	21.27	31.01	0.00	0.01	0.02	47.32	51.00	7.50	2.75
9	0.36	0.01	0.21	0.11	0.01	21.35	30.60	0.00	0.05	0.02	47.30	17.00	7.50	8.75
8	0.90	0.02	0.51	0.14	0.01	21.02	30.83	0.00	0.11	0.02	46.44	72.00	14.26	6.75
7	0.11	0.00	0.06	0.15	0.02	21.38	30.61	0.00	0.01	0.01	47.65	33.00	5.00	5.00
6	0.05	0.00	0.02	0.06	0.01	0.72	55.01	0.00	0.00	0.03	44.10	142.00	12.49	7.50
5	1.63	0.02	0.30	0.37	0.02	1.01	52.98	0.00	0.06	0.02	43.60	283.00	15.01	8.01
4	0.04	0.00	0.01	0.04	0.02	0.55	55.09	0.00	0.00	0.02	44.23	126.00	10.50	6.25
3	0.15	0.00	0.04	0.28	0.04	5.15	49.40	0.00	0.00	0.02	44.91	118.00	9.25	3.75
2	0.26	0.00	0.15	0.18	0.02	20.02	31.44	0.01	0.03	0.01	47.87	84.00	3.75	3.75
1	0.18	0.01	0.11	0.10	0.01	20.89	30.88	0.00	0.02	0.02	47.79	60.00	10.48	5.00

Tab. 1 - Geochemical composition and concentration of trace elements.

VAR.	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
SiO_2	0.031	1.634	-0.137	-0.183	-0.749
TiO_2	-0.214	1.469	-0.256	-0.080	0.052
Al_2O_3	-0.149	1.627	-0.280	-0.003	-0.509
Fe_2O_3	-0.325	1.252	1.166	0.045	-0.248
MnO	-0.174	0.044	3.456	-0.587	0.007
MgO	-0.473	0.168	0.483	3.635	0.008
CaO	1.747	-0.110	0.234	0.210	0.103
Na_2O	-0.295	1.034	-0.069	0.095	3.513
K_2O	-0.201	1.616	-0.411	-0.008	-0.754
P_2O_5	0.659	0.927	0.211	-0.117	-0.276
CO_2	1.637	-0.139	0.239	0.495	0.157
Sr	1.700	0.201	0.103	-0.013	-0.034
Zn	1.518	0.239	0.072	0.293	0.103
Cu	1.445	0.507	-0.147	0.047	0.286

Tab. 2 - Q-mode scaled varimax factor scores for the five factors.

ate rocks, and accounts for 1.7% of the total variance.

These five significant factors account for 97.73% of the total variance of the analyzed data. They are hereafter written as F1, F2, F3, F4, and F5.

Thus, using the factor loadings of the 86 studied samples on the five identified factors, a cluster analysis was undertaken. In this way, 7 sample groups were obtained (Tab. 3) which are characterized by similar geochemical behaviour.

Group 1 includes 50% of the analyzed samples and stands out because F1 is its main component (CaO, Sr, CO_2, Zn and Cu), and it identifies those samples with the greatest calcareous component. The sample having the highest factor loading for F1 is 69 (90% F1). Sample 77 is at the opposite end with 59% F1 and 20% F2.

The following samples belong to this group:

- 4, 5, 6, 11, 12, 13, 16, 17 - Level 2 (Serla Dolomite Rock);
- 23, 24, 25, 26, 27, 28, 29, 30, 31, 32 - Level 4 (Tiarfin Mount Dolomitic Limestones);
- 34 - Level 5 (Ammonitic Red Limestones);
- 44, 45, 46 - Level 6 (Livinallongo Formation);
- 47, 48, 49, 51, 52, 53, 59, 63, 65, 67, 68, 69, 71, 72, 73 - Level 7 (Light, Massive and Stratified Dolomites and Dolomitic Limestones);
- 74, 76, 77, 79, 81, 82 - Level 8 (Brown Stratified Limestones).

Group 2 accounts for 10% of the samples; sample

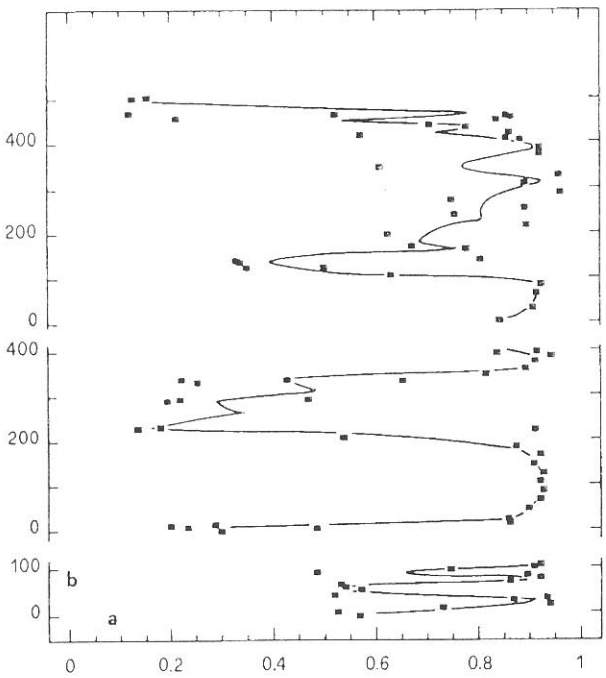

Fig. 5 - (a) Q-mode factor loadings on first factor (CaO, Sr, CO_2, Zn, Cu) of the samples; (b) sample distribution on sequence.

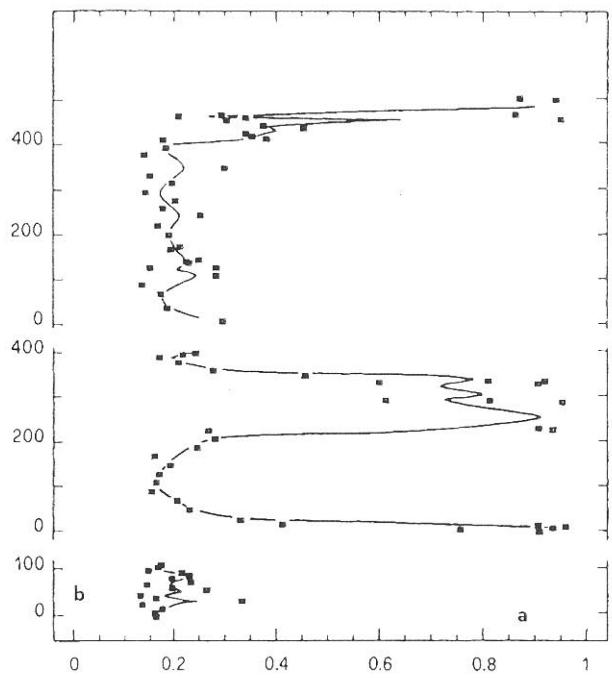

Fig. 6 - (a) Q-mode factor loadings on second factor (SiO_2, Al_2O_3, K_2O, TiO_2, Fe_2O_3, Na_2O) of the samples; (b) sample distribution on sequence.

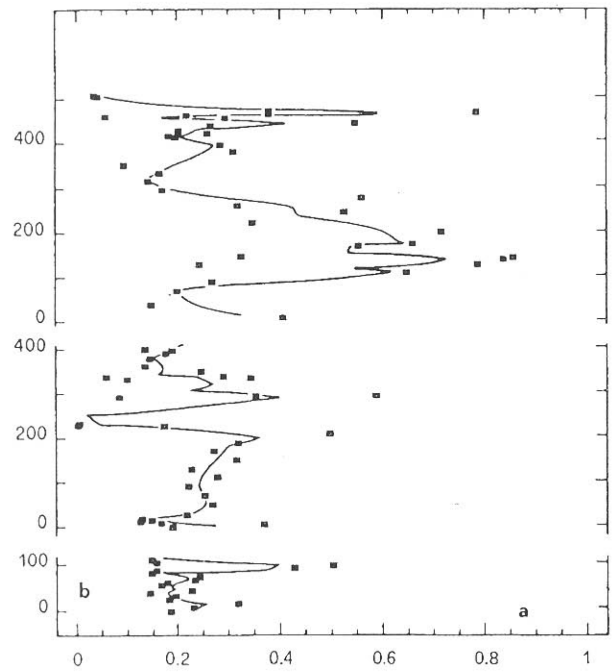

Fig. 7 - (a) Q-mode factor loadings on third factor (MnO) of the samples; (b) sample distribution on sequence.

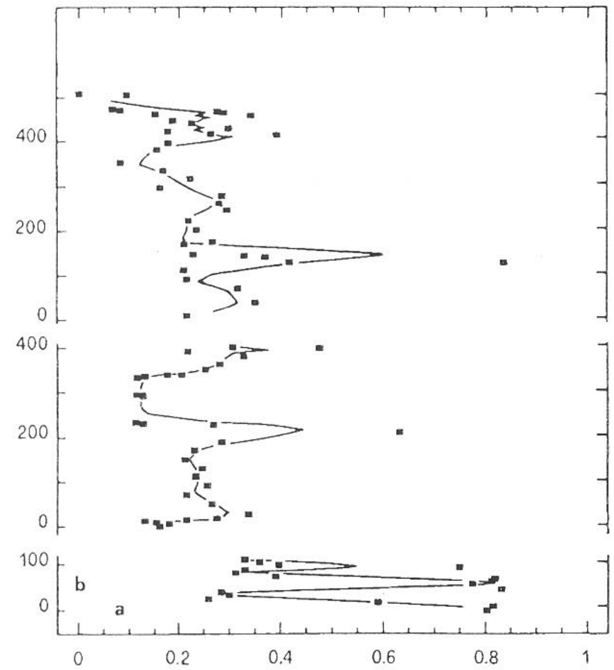

Fig. 8 - (a) Q-mode factor loadings on fourth factor (MgO) of the samples; (b) sample distribution on sequence.

	SAMPLES	GROUPS 1	2	3	4	5	6	7	
LEVEL 9	86							X	Violet sandstones
	85							X	
	84							X	
LEVEL 8	83				X				Brown stratified limestones
	82	X							
	81	X							
	80							X	
	79	X							
	78		X						
	77	X							
	76	X							
	75						X		
	74	X							
LEVEL 7	73	X							Light, massive and stratified dolomites and dolomitic limestones
	72	X							
	71	X							
	70					X			
	69	X							
	68	X							
	67	X							
	66		X						
	65	X							
	64		X						
	63	X							
	62		X						
	61		X						
	60		X						
	59	X							
	58				X				
	57				X				
	56			X					
	55				X				
	54		X						
	53	X							
	52	X							
	51	X							
	50		X						
	49	X							
	48	X							
	47	X							
LEVEL 6	46	X							Livinallongo Formation
	45	X							
	44	X							
	43							X	
	42						X		
	41						X		
	40							X	
	39							X	
	38						X		
	37							X	
	36							X	
	35							X	
LEVEL 5	34	X							Ammonitic red limestones
	33			X					
LEVEL 4	32	X							Tiarfin Mount dolomitic limestones
	31	X							
	30	X							
	29	X							
	28	X							
	27	X							
	26	X							
	25	X							
	24	X							
	23	X							
LEVEL 3	22							X	Anisian basin unit
	21							X	
	20							X	
	19						X		
	18							X	
LEVEL 2	17	X							Serla dolomite rock
	16	X							
	15		X						
	14			X					
	13	X							
	12	X							
	11	X							
	10			X					
	9			X					
	8			X					
	7			X					
	6	X							
	5	X							
	4	X							
	3			X					
LEVEL 1	2			X					Stratified dolomite rocks
	1			X					

Tab. 3 - Samples distribution on the seven groups.

50 is typical and has the highest percentage of F1 (71%) together with 16% F3, whereas sample 62 has the smallest percentage of F1 (39%) and the greatest of F3 (51%).

The following samples belong to this group:
- 15 - Level 2 (Serla Dolomite Rock);
- 50, 54, 60, 61, 62, 64, 66 - Level 7 (Light, Massive and Stratified Dolomites and Dolomitic Limestones);
- 78 - Level 8 (Brown Stratified Limestones).

Group 3 is represented by 12% of the overall samples. These are characterized by a calcareous-dolomitic composition, as shown by sample 56, which has 25% F1, and 66% F4. Sample 3 has the lowest content of F4 (39%) and has a calcareous component (F1) amounting to 53%.

This group consists of the following samples:
- 1, 2 - Level 1 (Stratified dolomite rocks);
- 3, 7, 8, 9, 10, 14 - Level 2 (Serla Dolomite Rock);
- 33 - Level 5 (Ammonitic Red Limestones);
- 56 - Level 7 (Light, Massive and Stratified Dolomites and Dolomitic Limestones).

Group 4 consists of 4 samples (5% of the total amount). They are characterized by the presence of F1

and F4 and a marked presence of F3; these are carbonate phase characterized by Fe_2O_3 and MnO. The samples of the fourth group are:
- 55, 57, 58 - Level 7 (Light, Massive and Stratified Dolomites and Dolomitic Limestones);
- 83 - Level 8 (Brown Stratified Limestones).

Group 5 consists of sample 70, revealing the presence of F1 and a considerable component of F5, made up of Na_2O.

In this cluster analysis, the first five groups are set against the other two groups, the sixth and the seventh, where a progressive percentage decrease of F1 and F4 can be noted, together with an increase in F2.

Group 6 has a varying factor composition. Sample 42 includes18% of the first factor, 65% of the second factor and 8% of the third factor. Conversely, sample 38 has 22% of F1, 37% of F2 and 34% of F3.

The following samples belong to this group:
- 19 - Level 3 (Anisian basin unit);
- 38, 41, 42 - Level 6 (Livinallongo Formation);
- 75 - Level 8 (Brown Stratified Limestones).

Group 7 is characterized by the silicate component (F2). Sample 21 is the most typical in the group (92% F2).

The opposite extreme is represented by sample 39 where 66% of F2 can be found, as well as a slight increase in F3, whereas the presence of F1 is irrelevant.

This group includes the following samples:
- 18, 20, 21, 22 - Level 3 (Anisian Basin Unit);
- 35, 36, 37, 39, 40, 43 - Level 6 (Livinallongo Formation);
- 80 - Level 8 (Brown Stratified Limestones);
- 84, 85, 86 - level 9 (Violet Sandstones).

Some significant conclusions on the different levels of the examined sequence can be drawn from the percentage values of the major and minor elements, from the concentrations of trace elements, and from the proposed statistical elaboration.

8.1. STRATIFIED DOLOMITE ROCKS (LEVEL 1, SAMPLES 1-2)

The lithotype constituting the rock is almost pure dolomite (mean values: dolomite 93.58%, calcite 4.8%, insoluble residue 1.59%). The numerical data for the element concentrations highlights that CO_2, CaO and MgO are the most typical oxides.

The two samples (1 and 2) defining the first level belong to the third group defined by the cluster analysis, and are characterized, respectively, by 61% and 64% F4 and by 32% and 27% F1 (Ca, Sr, CO_2, Zn and Cu). Their clear dolomitic nature, therefore, is confirmed. This lithotype must have been hypersaline and rich in oxygen.

8.2. SERLA DOLOMITE ROCK (LEVEL 2, SAMPLES 3-17)

The data gathered from the analyses carried out for this formation denote its mixed carbonate character; it is calcareous in its bottom part (mean values: calcite 90.20%, dolomite 8.51%, insoluble residue 1.28%), and in its top part (calcite 93.31%, dolomite 6.11%, insoluble residue 0.58%); and dolomitic in its intermediate part with two episodes of mean-composition: calcite 2.99%, dolomite 96.11%, insoluble residue 0.88%.

These variations in the dolomitic-calcareous characteristics are also highlighted by the statistical analyses. The intermediate character of sample 3, passing from the 1st to the 2nd level, is followed by the typically calcareous character of samples 4, 5 and 6 (75% to 88% F1, group 1) and the typically dolomitic character of the subsequent samples 7, 8, 9 and 10 (57% to 66% F4, 3rd group). In the remaining samples 14, 15, 16 and 17, a gradual passage occurs from a dolomitic type, sample 14 (53% F4) to a carbonate type (85% F1) of sample 17. The relative importance of F3 (Fe_2O_3 and MnO, 18% and 25%) in samples 14 and 15 is to be stressed.

On the basis of these data, the development environment of this unit is highly articulated, with rather significant variations in the salinity and oxygenation coefficients.

8.3. ANISIAN BASIN UNIT (LEVEL 3, SAMPLES 18-22)

A study of the data revealed a considerable percentage of insoluble residue (mean value 56.11%) in the samples belonging to this level. This indicates that the carbonate component is extremely reduced (mean values: dolomite 11.72%, calcite 32.15%) as compared with the previously analyzed levels.

The most abundant oxide is SiO_2 (38.92%), followed by CaO (21.57%) and CO_2 (18.18%), and thereafter by Al_2O_3 (10.49%), Fe_2O_3 (4.16%), K_2O (3.26%), MgO (2.56%) and Na_2O (0.07%).

TiO_2 is the most abundant of the minor elements (0.50%), followed by MnO and P_2O_5 (0.07%).

The statistical elaboration clearly shows the silicate character (F2: Si, Al, K, Ti, Fe) of these samples (82% to 92%), with the exception only of sample 19 which has a mixed composition (23% F1, 57% F2, 14% F3) where, however, the silicate component prevails.

8.4. TIARFIN MOUNT DOLOMITIC LIMESTONES (LEVEL 4, SAMPLES 23-32)

The lithotype is a fairly pure limestone (mean values: calcite 96.14%, dolomite 3.19%, insolouble residue 0.67%). This is confirmed by the high percentage of all samples belonging to F1, with values between 74% and 86%. The consistency of the values suggests that this unit's deposition was not subjected to special events, and apparently started as aragonite mud which subsequently became calcite (BENCINI & TURI, 1974).

8.5. AMMONITIC RED LIMESTONES (LEVEL 5, SAMPLES 33-34)

This unit has a width of 15-50 cm, and a scant lateral continuity. This variability can be found also in the chemical composition of the lithology of this small horizon.

Chemical analyses revealed that it is definitely composed of carbonate, with a calcareous-dolomitic base and a typically calcareous roof, and a very small amount of insoluble residue (2.12%).

Sample 33 has a dolomitic nature, with a considerable presence of F3 (MnO and Fe_2O_3, 25%), whereas sample 34 is clearly composed of carbonate (83% F1).

8.6. LIVINALLONGO FORMATION (LEVEL 6, SAMPLES 35-46)

Analytical data highlight the subdivision of the unit into three parts: a lower, having an almost completely silicate character, an intermediate of a prevailing arenaceous-carbonate component, and an upper which is typically calcareous.

The lower part is characterized by abundant SiO_2 (mean value 69.32%), followed by Al_2O_3 (13.78%) and K_2O (7.11%), and then Fe_2O_3 (2.72%), CaO (2.63%), MgO (1.79%), CO_2 (1.78%) and Na_2O (0.45%).

Among minor elements, only TiO_2 (0.31%) and P_2O_5 (0.05%) seem to be significant.

Among trace elements, the small content of Sr (30.6 ppm) is highlighted, confirming its direct relationship to CaO contents, whereas Cu (24.16 ppm) and Zn tend to increase slightly only in sample 37 (18.75 ppm).

The silicate character of the first part of the level (samples 35-37) is confirmed by the high F2 percentage (82% to 91%).

The intermediate part (samples 38-43) is characterized by a considerable decrease in the silicate phase and by an increase in the carbonate phase.

The most abundant of the determinant elements is SiO_2 (mean value 34.84%), followed by CaO (28.38%) and CO_2 (20.64%), then Al_2O_3 (7.51%), Fe_2O_3 (3.13%), MgO (2.32%), K_2O (2.13%) and Na_2O (0.46%).

The most abundant of the minor elements is TiO_2 (0.36%), followed by MnO (0.11%) and P_2O_5 (0.08%).

In this level, Zn (mean value 14.4 ppm) and Cu (mean value 29.8 ppm) have the highest levels of the entire sequence. Their geochemical behaviours do not have any particular affinity, but Cu tends to increase in the silicate phases.

The high percentage of K_2O in the lower portion samples 35, 36 and 37, and in the intermediate portion samples 40 and 43 is to be linked with the abundance of Al_2O_3, as they together probably form potassium alluminium silicates.

This intermediate part of the level acts, therefore, as a passage to the carbonate upper part. Statistical processing highlights the fact that this passage has the same trend in the two successive sample groups: 38, 39, 40 and 41, 42, 43. They both show an increase from the 1st to the 3rd sample of the two groups towards high F2 percentages (silicate character), together with a decrease in the percentage of the carbonate component (F1) and even more so of F3 (MnO and Fe_2O_3).

The upper portion of this unit (44-46) is essentially characterized by CaO (mean value 53.79%) and CO_2 (42.89%). The percentage of F1 (carbonate phase) ranges from 67% to 83%.

The lower part belongs to an environment characterized by important volcanoclastic input linked with probably acid magmatic phenomena which led to the development of the "pietra verde". The intermediate portion represents an environment in which volcanoclastic supplies tend to be gradually reduced and mixed with materials belonging to the new carbonate environment which is about to be developed. The upper part can be ascribed to a rather uniform calcareous sedimentation environment, given the small presence of terrigenous supply (insoluble residue 1.9%).

8.7. LIGHT, MASSIVE AND STRATIFIED DOLOMITES AND DOLOMITIC LIMESTONES (LEVEL 7, SAMPLES 47-73)

The lithotype apparently forming the unit is an almost pure limestone (mean values: calcite 95.07%, dolomite 4.04%, insoluble residue 0.89%).

The central part of the level with the first group of samples (55-58) differs in that it is characterized by a medium-low presence of F1 and F4 and a high percentage of F3 (62 to 73%). These are dolomitic-carbonate phases, rich in Fe and Mn. A second successive group of samples (60-66), with the exception only of samples 63 and 65 which are typical carbonate samples, has a more marked carbonate character but still with a consistent presence of F3 (Fe, Mn).

The oxides characterizing this calcareous unit are essentially CaO (54.49%), CO_2 (43.97%) and MgO (0.88%).

A few above-average percentages of Na_2O in samples 54, 59, 68 and 70 are to be noted.

The dolomitic level is characterized by CO_2 (mean value 45.60%), CaO (36.71%), MgO (15.28%), Fe_2O_3 (1.82%) and MnO (0.27%).

These results reveal that a rather uniform and prolonged platform environment, with scant terrigenous supply, developed at the end of the "Livinallongo Formation", and that paleogeographic conditions changed only briefly with the above-mentioned dolomitic episode.

8.8. BROWN STRATIFIED LIMESTONES (LEVEL 8, SAMPLES 74-83)

The prevailing lithotype in this unit is black stratified limestone (calcite 93.00%, dolomite 4.79%, insoluble residue 2.18%), with frequent silt insertions. The chemical composition of sample 80 differs from that of the other samples belonging to this sequence since it represents one of these insertions.

The oxides characterizing this formation are CaO (mean value 53.56%), CO_2 (43.03%), SiO_2 (1.45%), MgO (1.04%), Fe_2O_3 (0.41%) and Al_2O_3 (0.29%).

The chemical composition of sample 75 is very close to the unit average. However, it has relatively high concentrations of K_2O (0.3%) and P_2O_5 (0.20%); furthermore, MnO has higher values in samples 78 and 83 (0.14% and 0.30%). These values are probably due to a local situation which is very difficult to interpret from a paleoenvironmental point of view.

With reference to trace elements, Cu (27 ppm) reaches a considerable concentration in sample 80 (silt intercalation), thus confirming its affinity with the silicate phases.

Statistical surveys confirm the different natures of samples 75 and 80 compared with the decidedly calcareous type in this level (61 to 75 in F1).

On the basis of the data, this unit represents a carbonate platform, with a gradual increase of terrigenous supplies and development towards a neritic environment.

8.9. VIOLET SANDSTONES (LEVEL 9, SAMPLES 84-86)

This unit represents the last horizon of the studied sequence and is formed from quartzose-silicate elements with variable granulometry.

The bottom part contains a considerable CaO component (8.57%) compared with the rest of the sequence. This feature demonstrates a transition phase from the platform conditions of the previous unit to the typically detrital and silicate conditions of the upper portion of this level.

The unit is characterized by abundant (mean values) SiO_2 (70.11%), followed by Al_2O_3 (14.20%) and Fe_2O_3 (4.03%). The following elements come next: CaO (2.85%), K_2O (2.57%), CO_2 (2.49%), MgO (1.37%) and Na_2O (1.21%).

The most abundant minor element is TiO_2 (0.69%), followed by MnO (0.10%) and P_2O_5 (0.05%).

The statistical elaboration confirms the silicate nature of the level (74% to 88% F2), and thus the classification was made according to chemical data.

Of the trace elements, only Cu seems to be significant (45 ppm), thus confirming its abundance in high silicate concentrations (insoluble residue: 91.50%).

The development environment of this unit was detrital and had marked energy variations which generated reducing conditions.

This analysis reveals that SiO_2, Al_2O_3, Fe_2O_3, K_2O, Na_2O, TiO_2, Cu and Zn are relatively abundant in these lithological unit with high terrigenous supplies. Indeed, their variations can be clearly related to the insoluble residue content.

The lithophilous elements (Si, Al, Fe, K, Na and Ti) are believed to be mainly in the form of quartz, feldspars and/or clay minerals, given the clear reciprocal relations which were observed, whereas the calcophilous elements (Cu and Zn) can be found in the form of sulphides.

The Fe distribution in the carbonate rocks is characterized by a relative increase of its concentration in a few samples of dolomitic composition. This indicates a dolomitization in a shallow and oxygen-rich sea platform environment (BENCINI & TURI, 1974).

The contents of Na and K should indicate environmental paleosalinity (LAND & HOOPS, 1973). Data analyses, however, do not reveal any consistent variation of concentration which is not linked to external supplies to the basin, i.e. to the insoluble residue.

The behaviour of Sr can be closely linked to that of Ca; it can replace Ca in the aragonite lattice and, to a lesser extent, in the calcite lattice. It decreases in diagenesis and can therefore be considered as a good diagenesis indicator. According to COMIN CHIARAMONTI et al. (1983) carbonate lithologies with a greater Sr/Ca ratio went through a limited diagenesis; another hypothesis is that this diagenesis occurred in a rather protected environment.

9. CONCLUSIONS

Stratigraphic and geological data, together with geochemical analyses of the samples studied, provided a definition of the examined stratigraphic sequence levels.

It was also possible, in some cases, to give a detailed description within the geological formations and lithologies.

The application of the proposed statistical methods allowed a systematic analysis of the geochemical data. It also characterized the lithological types of the different geological formations from a geochemical point of view, thus confirming the stratigraphic results already obtained, and highlighting some geochemical anomalies linked to specific geological situations.

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