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REPARTITION AND PALEOGEOGRAPHICAL INTERPRETATION OF VOLCANOCLASTIC AND PELAGIC SEDIMENTS OF THE LIVINALLONGO FORMATION (ITALIAN DOLOMITES)

by P. Cros & P. Houel*)

Summary

The detailed lithostratigraphy and sedimentology of the volcanoclastic and pelagic strata making up the Livinallongo Formation (Middle Triassic) in the Italian Dolomites allow us to point out two pyroclastic stages of sequential deposition ("pietra verde") and to show some relationships to extensional tectonic movements, acid volcanism and the euxinic sedimentation in narrow basins connected with mobile sills. Some comparisons with the neighbouring Carnic Alps are useful.

The "pietra verde" particles are essentially of pyroclastic origin but locally also epiclastic, with a mixture of pelagic material. The magmatic characters are partially concealed by the lack of in place lava flow. But, on the basis of the existing lithic elements of the crystals with their inclusions, it is possible to say that the tuffites forming the "lower pietra verde" are coming from a water-rich magma of late differentiation and trachy-andesitic composition, and those forming the "upper pietra verde" are of rhyolitic to rhyodacitic composition.

The sedimentological analysis of the pietra verde shows the various sequential modalities of their deposition, in close relationship to the sea-bottom morphology. The graded-bedding of particles, according to their size and density, the order of the sedimentary structures, the homogeneity and poor shaping of the particles, and the reworked intraclasts (nodule breccia) at the bottom and the occurrence of Radiolaria at the top of the sequences are characteristics of the "pyroturbidites" of the "lower pietra

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verde". Some correlations are possible along about 20 km and point out the importance (more than 1 km^3 for the bigger pyroclastic layer), the control by the submarine morphology and distance from the supposed volcanic centres. The four sequences are interpreted either as "pyroturbidites" (subaqueous pyroclastic flows) or as distal submarine parts of ignimbrites as well as continental ash-flow; between them, in the pelagic realm, some reworking of ash-fall and lutites took place at the top of the pyroclastic flow. On the other hand, the numerous "upper pietra verde" sequences are interpreted as a classical turbidity current accumulation of epiclastic origin, coming from the progressive reworking of a volcanic buildup of chiefly pyroclastic nature. The regional correlations between sequences are hard to establish, except for the first "upper pietra verde" strata which contain volcanic quartz in the crystalline and lithic fraction; this points to its regional lithostratigraphic value. Channel sedimentation prevails in the coarser-grained strata.

Their heteropical relationships to the "upper Plattenkalk" facies is proved by the correlations and the mixture of pelagic and tuffitic material in the banded limestones.

It is possible to link each of the "lower pietra verde" sequences with a volcanic event of regional extension; on the other hand, the "upper pietra verde" turbidites do not allow the stratigraphic individualization of the eruptive events, but it is possible to notice a mineralogical evolution: with quartz at the bottom and basic plagioclases and green hornblende at the top.

The three pelagic facies are as follows: clear grey nodular limestone with bioturbation structures, dark siliceous, finely banded limestone, not bioturbated, and marly carbonate subnodular or regularly bedded strata, bioturbated and so-called "Vedessana facies". In general these three facies have the same microfossil content in common: Radiolaria, *Daonella*-type of pseudo-planctonic lamellibranchs. The facies changes between the pelagic sediments point out the main interconnection between the subcrustal activity (magmatic and epeirogenic) and the sedimentation. They allow a paleogeographical interpretation of either the sea-bottom morphology or the localization of. volcanic centres. The replacement of the terrigenous supply of the underlying strata (Ambata Formation) by the volcanic supply in the Livinallongo Formation coincides with the development of the unbioturbated facies eastward and the main blooming of the pelagic microfaunas. The role played by a layer of anoxic water may explain the facies changes between the dark, unbioturbated, anaerobic banded limestone and the nodular or subnodular dysaerobic limestone, the first of deeper marine origin and the second being shallower. These dysaerobic sediments pass laterally to the calcarenitic "mixed facies", typical of the biogenous carbonate platform edges and slopes.

The differential bathymetry is, by this way, pointed out for instance in the eastern part of the Cadore district: the deposition of the first "pietra verde" strata is outlined by the disappearance of the euxinic facies and the general extension of the nodular limestone. The tuffites coming from the south overrun the deeper parts of the basin. In the same way, the first cinerites of the "upper pietra verde" unit preceded for a short time the end of the bioturbation and the renewal of the euxinic conditions in the whole basin ("upper Plattenkalk"). The two tuffitic stages of deposition are separated by a purely pelagic stage in the whole basin (Italian Dolomites and Carnic Alps). The main part of the tuffitic supply is supposed to come from the south or south-east during the "lower pietra verde" stage, except for the so-called "Pecol Lungo tuffites" of the eastern Dierico basin (central Carnic Alps), where the tuffitic supply is coming from the north.

A north-western origin is also supposed for part of the "upper pietra verde" stage in the Badia Valley (western Dolomites); during that time the ash-falls are dispersed in the whole region.

This paleogeographical framework is explained by a synsedimentary extensional tectonic evolution which favours at the same time the magmatic extrusions, the restricted biotic conditions in narrow and moderately deep basin portions, connected by mobile sills.

REPARTITION DES SEDIMENTS VOLCANOCLASTIQUES ET PELAGIQUES FORMATION DE LIVINALLONGO (DOLOMITES ITALIENNES)

Resumé

La lithostratigraphie fine et la sédimentologie des couches volcanoclastiques et pélagiques de la Formation de Livinallongo (Trias moyen) des Dolomites italiennes ont permis d'individualiser deux phases de dépôt pyroclastique à caractère séquentiel ("pietra verde") et de montrer les relations entre tectonique distensive, volcanisme acide et euxinisme dans les bassins étroits, reliés par des seuils mobiles. Elles permettent d'établir des comparaisons avec les Alpes Carniques.

La "pietra verde" est constituée de particules d'origine essentiellement pyroclastique et localement épiclastique. Elle montre aussi un mélange de matériel pélagique. La caractérisation du magmatisme est genée par l'absence de lave en place sur le terrain d'étude. Cependant, grâce à l'analyse des éléments lithiques, des cristaux et de leurs inclusions, il est vraisemblable que les tuffites de la "pietra verde inférieure" proviennent d'un magma riche en eau, de fin de differenciation, de composition trachy-andésitique, celle de la "pietra verde supérieure" de composition rhyolithique à rhyo-dacitique.

L'analyse sédimentologique de la "pietra verde" a montré que le dépôt des tuffites se faisait selon plusieurs mode séquentiels, en relation étroite avec la morphologie du fond marin. Le granoclassement des particules par taille et par densité, l'étagement des structures sédimentaires, l'homogénéïté et le faible façonnement du matériel, le remaniement d'intraclastes (brèche de nodules) au mur et la présence de radiolaires au toit de la séquence sont des caractères typiques des "pyroturbidites" de la "pietra verde inférieure". Des corrélations sur une vingtaine de kilomètres ont montré l'importance (plus d'un kilomètre cube pour la plus importante) et le contrôle par la morphologie du bassin et la distance par rapport aux centres volcaniques supposés. Ces quatre séquences, interprétées soit comme des pyroturbidites (subaqueous pyroclastic flows), soit comme des terminaisons sous-marines et distales d'ignimbrites ou d'"ash-flow" continentaux, sont séparées par des microséquences de remaniement des cinérites et des lutites pélagiques sommitales des pyroturbidites.

Par contre, les séquences multiples de la "pietra verde supérieure" sont interpretées comme une accumulation de turbidites classiques, épiclastiques, provenant du démantèlement progressif d'un édifice volcanique à dominante pyroclastique. Les corrélations régionales sont difficiles à

établir; cependant les premières assises de la "pietra verde supérieure" sont caractérisées par la présence de quartz volcanique dans la fraction cristalline et lithique, ceci souligne leur valeur dans les corrélations régionales. La chenalisation est trés forte dans les termes grossiers. L'hétéropie avec le faciès "Plattenkalk" est prouvée par les corrélations et la présence d'un faciès de mélange rubané pélagico-tuffitique.

En conclusion, les faits permettent de rattacher chacune des séquences majeures de la "pietra verde inférieure" à un èvènement volcanique d'importance régionale, alors que les turbidites de la "pietra verde supérieure" ne permettent pas d'isoler dans le temps les èvènements èruptifs. Elles tèmoignent, cependant, d'une évolution minéralogique: quartz à la base, plagioclases basiques et hornblende verte au sommet.

Les faciès pélaqiques sont au nombre de trois: le calcaire noduleux gris-clair à structures de bioturbation, les dalles calcaréo-siliceuses sombres, rubanées, non bioturbées et les alternances marno-carbonatées subnoduleuses, bioturbées, dites de type "Vedessana". Ces trois faciès possèdent globalement le même contenu en radiolaires et lamellibranches pseudo-planctoniques de type Daonelles. Les variations de faciès des sédiments pélagiques jalonnent les principales phases d'interférence entre l'activité endogène, magmatique et épirogénique, et la sédimentation. Elles permettent de reconstituer la paléogéographie des fonds marins et des centres éruptifs. Le relai des apports terrigènes de la Formation sous-jacente d'Ambata par les apports volcanoclastiques de la Formation de Livinallongo correspond à l'extension, vers l'Est, des faciès non bioturbés et à l'épanouissement de la faune pèlagique. L'existence d'un euxinisme du fond dû à un seuil sous-marin peut expliquer le passage de faciès entre un "Plattenkalk" sombre non bioturbé, anaérobie et profond et des alternances subnoduleuses ou noduleuses, bioturbées, dysaérobies moins profondes. Ces derniers sédiments passent latéralement à des couches "mixtes" calcarénitiques typiques des bordures de plates-formes biogènes.

Une bathymétrie differentielle est ainsi mise en évidence, par exemple dans la partie orientale du Cadore. La mise en place de la première assise de "pietra verde" est marquée par la disparition des faciès euxiniques et la généralisation du calcaire noduleux. Les tufs en provenance du Sud envahissent les parties les plus profondes du bassin. De même le dépôt des premières cinérites de la "pietra verde supérieure" précède de peu la fin des bioturbations et la reprise de l'euxinisme dans l'ensemble du bassin de dépôt ("Plattenkalk supérieur").

Ces deux phases tuffitiques séparées par une phase purement pélagique caractérise les couches de Livinallongo dans les Dolomites et la Carnie. L'essentiel des apports tuffitiques viennent du Sud ou du Sud-Est pour les "pietra verde inférieures" (bassin de Livinallongo, de Cadore, de Sappada), exception faite des tuffites de "Pecol Lungo" du bassin de Dierico (Carnie centrale) qui viennent du Nord. Cèst aussi le cas pour une parties des "pietra verde supérieures" du Val Badia, tandis que les retombées cinéritiques s'étalent sur toute la région.

Ce contexte paléogéographique s'explique par une tectonique distensive syn-sédimentaire qui permet à la fois la montée du magma, la création des conditions biologiques de dépôt dans des portions de bassin modérément profondes et étroites communiquant par des seuils mobiles.

VERTEILUNG UND PALÄOGEOGRAPHISCHE INTERPRETATION VULKANOKLASTISCHER SEDIMENTE DER BUCHENSTEINER SCHICHTEN (LIVINALLONGO-FORMATION, MITTLERES LADIN, ITALIENISCHE DOLOMITEN)

Zusammenfassung

Zwei verschiedene pyroklastische Ablagerungsphasen (Pietra verde) konnten durch lithostratigraphische und sedimentologische Untersuchungen in den vulkanoklastischen und pelagischen Sedimenten der Buchensteiner Schichten der italienischen Dolomiten herausgearbeitet werden. Die Sedimentation erfolgte unter Einfluß von distensiver Tektonik, saurer vulkanischer Tätigkeit und auxinischen Ablagerungsbedingungen in schmalen Beckenzonen, die durch submarine Schwellen getrennt waren. Die Untersuchungen erlauben auch einen Vergleich mit den benachbarten Karnischen Alpen.

Die Pietra verde besteht hauptsächlich aus pyroklastischen und örtlich auch epiklastischen Bestandteilen. Auch Beimengungen von pelagischem Material kommen vor.

Der Magmencharakter konnte, bedingt durch das Fehlen von Laven im Sedimentationsgebiet selbst, nur über die Analyse der vulkanoklastischen Bestandteile (Kristalle und Einschlüsse) ermittelt werden. Dabei stellte sich heraus, daß die "untere Pietra verde" einem wasserreichen, spätdifferenzierten Magma mit trachyandesitischer Zusammensetzung entstammt. Dagegen zeigen die Tuffite der "oberen Pietra verde" eine rhyolithische bis rhyodazitische Zusammensetzung.

Die Sedimentation der Pietra-verde-Abfolgen erfolgte in mehreren Sequenzen in deutlicher Abhängigkeit zur Morphologie des Meeresbodens. Korngrößenverteilung, Anordnung der sedimentären Strukturen, Homigenität und schwache Rundung der Körner als auch die Resedimentation von Intraklasten (= Knollenbreccie) im Liegenden der Sequenzen, und das Vorkommen von Radiolarien im Hangenden, sind typische Merkmale von sogenannten Pyroturbiditen der "unteren Pietra verde" Die Verbreitung über einen Raum von mehr als 20 km Längserstreckung - eine der mächtigeren Sequenzen weist eine Kubatur von mehr als 1 km^3 auf - deutet auf den Einfluß der submarinen Morphologie und auf die Nähe der angenommenen vulkanischen Zentren hin. Die vier Sequenzen werden interpretiert als "Pyroturbidite" (subaqueous pyroclastic flows), als distale, submarine Teile kontinentaler Ignimbrite oder auch als Aschenniederschläge. Am Top der Pyroturbidite kann eine Aufarbeitung von Aschen und Lutiten vorkommen.

Die zahlreichen Sequenzen der "oberen Pietra verde" werden dagegen als klassische Turbidite mit Anlagerung von epiklastischem Material interpretiert. Das Material entstammt einer fortschreitenden Aufarbeitung von vulkanischen, vorwiegend pyroklastischen Aufbauten. Abgesehen von den ersten Schichten der "oberen Pietra verde" ist eine regionale Korrelation der Sequenzen nur schwer möglich. Die ersten Schichten der "oberen Pietra verde" sind durch das Vorhandensein von vulkanischem Quarz gekennzeichnet. Dies scheint von regionaler Bedeutung zu sein. Ebenso herrscht hier bei grobkörniger Sedimentation Rinnenbildung vor. Die Faziesheteropie mit dem "oberen Plattenkalk" ist durch Korrelationen und durch das Zusammenvorkommen von pelagischem und tuffitischem Material in den gebänderten Kalken erwiesen.

Jede der bedeutenderen Sequenzen der "unteren Pietra verde" kann mit einer regional wichtigen vulkanischen Tätigkeit in Zusammenhang gebracht werden. Die Turbidite der "oberen Pietra verde" erlauben dagegen keine zeitliche Trennung der vulkanischen Ereignisse. Allerdings kann eine auffallende Veränderung in der mineralogischen Zusammensetzung beobachtet werden: Quarz im Liegenden und basischer Plagioklas und grüne Hornblende im Hangenden.

Drei verschiedene pelagische Fazies sind erkennbar: hellgraue, knollige Kalke mit Bioturbationsstrukturen, dunkle, SiO_2-reiche, gebänderte Plattenkalke ohne Bioturbation, und mergelige, schwach knollige oder regelmäßig geschichtete Karbonate mit Bioturbationsstrukturen, die als "Vedessana-Fazies" bezeichnet werden. Alle drei Fazies haben generell den gleichen Mikrofossilinhalt: Radiolarien und pseudoplanktonische, dünnschalige Lamellibranchiaten (*Daonella*-Typus). Die Fazieswechsel innerhalb der pelagischen Sedimentation deuten auf wesentliche Zusammenhänge zwischen subkrustaler Aktivität (Magmatismus und Epirogenese) und Sedimentation hin. Sie ermöglichen mit einer paläogeographischen Analyse insbesondere Aussagen über die Meeresbodenmorphologie und die Lokalisierung von eruptiven Zonen.

Der Übergang von terrigen beeinflußter Sedimentation in der liegenden Ambata-Formation zu vulkanisch beeinflußter Sedimentation in den Buchensteiner Schichten fällt zusammen mit der Entwicklung der nicht bioturbaten Fazies gegen Osten hin und dem Hauptaufblühen pelagischer Mikrofaunen. Euxinische Ablagerungsbedingungen an der Rückseite von Schwellenzonen können die Faziesübergänge zwischen den dunklen, anaeroben und in tieferem Wasser abgelagerten Plattenkalken (ohne Bioturbationsstrukturen) und den flaserigen oder knolligen, dysaerobischen Kalken flacheren Wassers (mit Bioturbationsstrukturen) erklären. Die dysaerobischen Sedimente gehen lateral in eine kalkarenitische "gemischte Fazies" über, wie sie für Randzonen der Karbonatplattformen typisch ist.

Unterschiedliche Beckentiefen konnten z.B. für den Raum östlich von Cadore festgestellt werden: Die Sedimentation der ersten Pietra-verde-Lagen ist gekennzeichnet durch das Verschwinden der euxinischen Fazies und die generelle Ausbreitung der Knollenkalke. Die aus dem Süden stammenden Tuffe bedecken die tieferen Beckenteile. In ähnlicher Weise erfolgten die ersten Aschenablagerungen der "oberen Pietra verde" kurz vor dem Nachlassen der Bioturbation und dem neuerlichen Einsetzen euxinischer Ablagerungsbedingungen im gesamten Beckenareal ("oberer Plattenkalk"). Die beiden tuffitischen Phasen werden von einer rein pelagischen Ablagerungsphase unterbrochen, was sowohl für Buchensteiner Schichten der Dolomiten als auch der Karnischen Alpen kennzeichnend ist. Für den Hauptteil des tuffitischen Materials wird ein südliches oder südöstliches Herkunftsgebiet angenommen. Dies gilt für die Beckenzonen von Buchenstein, Cadore und Sappada. Das Becken von Dierico (mittlere Karnische Alpen) bildet eine Ausnahme. Für die sogenannten "Pecol-lungo-Tuffite" wird ein nördliches Herkunftsgebiet angenommen. Für einen Teil der "oberen Pietra verde" des Gadertales (westliche Dolomiten) erfolgte die Schüttung aus dem Nordwesten. Aschenregen sind hingegen über die gesamte Region verbreitet.

Die geschilderten paläogeographischen Zusammenhänge können am besten durch eine synsedimentäre Dehnungstektonik erklärt werden. Diese hat sowohl das Aufsteigen von Magma ermöglicht als auch eine kleinräumige Gliederung des Ablagerungsraumes in schmale Beckenzonen mit eingeschränkten Lebensbedingungen und verbindende flache Schwellenzonen hervorgerufen.

Contents

INTRODUCTION

This revision of the Livinallongo strata in the Dolomites results from the field and laboratory study of P. HOUEL (1979) and from a collective sedimentological contribution on the Ladinian and Carnian volcano-sedimentary basins and from the synchronous carbonate platforms (CROS, 1974, 1979; CROS & FRYSSALAKIS, 1982; CROS & FREYTET, 1981; LAPOINTE, 1981).

The Livinallongo Formation is well known for its pelagic acid-tuffitic strata. VIEL (1979) has given an accurate stratigraphical definition of them. We may recall that theoretically the lower and upper boundaries of this formation have their best definition in the pelagic areas where they lie in continuity above the basinal Upper Anisian Ambata Formation (ASSERETO & PISA, 1978) as well as where they are covered by the Upper Ladinian pelagic and tuffitic Aquatona Formation (VIEL, 1979). In the heteropical Anisian platform areas of the Contrin Formation (= Upper Serla Formation) the Ladinian basin facies are clearly transgressive (CROS, 1974, 1979). The siliceous or dolomitic dark limestones, also called here "Plattenkalk" (German name of flag-limestone) for reasons of simplifications, and the grey nodular limestones (Knollenkalk) are, along with the tuffitic strata, called "pietra verde", the main and most typical facies of the Livinallongo Formation.

Various lithological subdivisions had been proposed. So NÖTH (1929) has distinguished three parts: the upper Muschelkalk Plattenkalk, the Knollenkalk and the pietra verde of the lower Buchenstein (= Livinallongo), the Plattenkalk and the pietra verde of the upper Buchenstein. ROSSI (1962, 1964, 1965) observes four units, around the Marmolada massive: siliceous and calcareous rhythmites at the bottom, followed by nodular limestones and pietra verde and banded and laminated limestones at the top. BACELLE SCUDELER (1972) described, at the top of the Anisian dolomites, four pelagic and tuffitic units. LAGNY (1974) distinguished in the western Carnic Alps, from bottom to top: a basinal unit called later on Ambata Formation, then a first pietra verde unit resulting from a first stage of volcanic activity, followed by a nodular limestones of Lower Ladinian (Fassanian) age; a second volcanic stage formed another unit of pietra verde tuffites; all is covered by a dark pelagic siliceous limestone unit of Upper Ladinian (Longobardian) age. Finally VIEL (1979) put the upper boundary of this formation just under the pelagic and acid tuffitic Upper Ladinian strata of the Aquatona Formation containing "Zoppe" tuffitic member.

Nevertheless, ASSERETO, BRUSCA, GAETENI & JADOUL (1977) and other authors admit, without a better knowledge of the facies evolution, that there seems to be no constant lithostratigraphic order.

A stratigraphical problem remains when we consider the relations of the Livinallongo Formation to the ammonite zones. The stratigraphical position and equivalence have been recently discussed (see SZABO et al. 1979; BALOGH, 1981) between the Aploceras avisianus zone (ASSERETO, 1969) characterizing the uppermost Anisian (Upper Illyrian) and the classical Protrachyceras zone of the lowermost Ladinian (Lower Fassanian). The two zones seem to be time-equivalent but facies-separated and thus ought to be gathered in the same substage (Upper Illyrian or Lower Fassanian). So they may be conveniently gathered at the base of the Livinallongo Formation, grouping all the strata lying above the Ambata Formation (Paraceratites trinodosus zone) in the Livinallongo Formation.

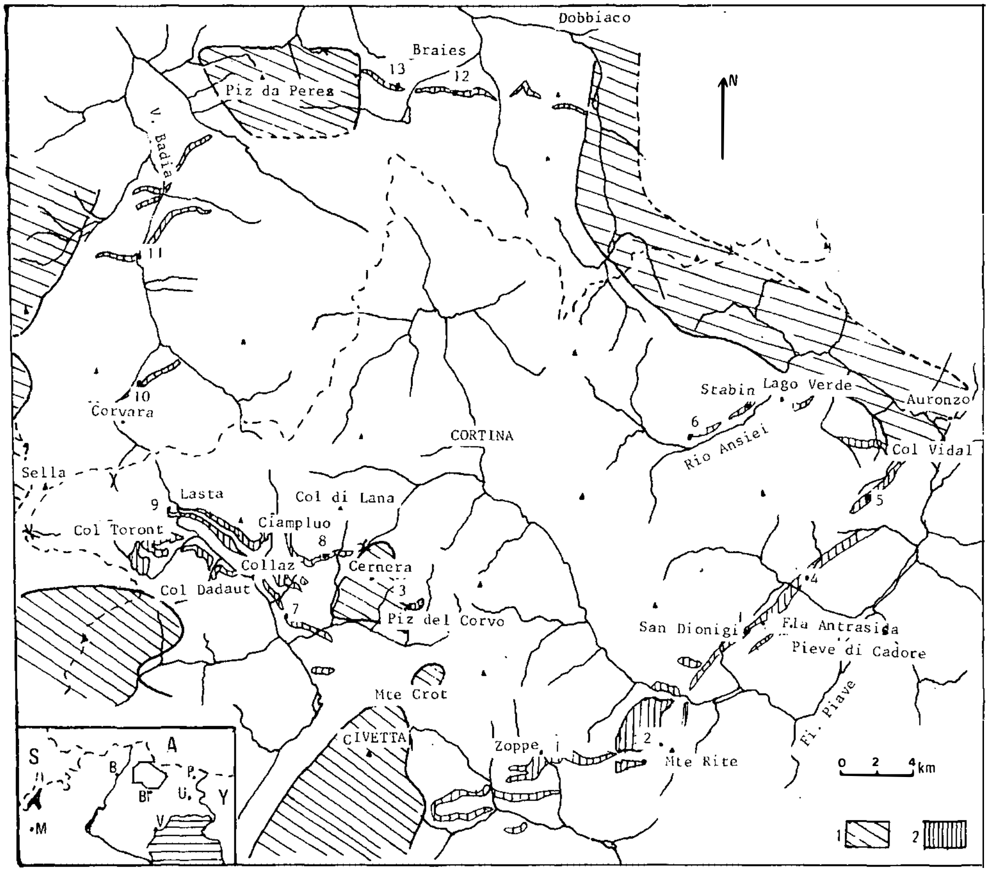


Fig. 1:

Localization map of the Ladinian basin in the Dolomites. Numbers 1-13: section position. 1: Zoppe; 2: Col Alto; 3: Piz del Corvo; 4: Valle Vadessana; 5: Pian di Buoi; 6: San Marco; 7: Villagrande; 8: Ciampestrin; 9: Cherz; 10: Poz de Corvara; 11: Pedraces; 12: Rio Schade; 13: Novalino. Symbols: 1: carbonate platforms; 2: Livinallongo Formation outcrops. M: Milano; B: Bolzano; Bl: Belluno; U: Udine; P: Paularo.

Boundaries of the volcano-sedimentary basin (fig. 1)

The main outcrops studied are localized in the central and estern Dolomites. Their extension decreases from south to north ; westward the basin is restricted, either by the Ladinian biogenous carbonate platforms or by the paleoreliefs outcoming from the tectonized Anisian platform. The pelagic basin may be divided into two main regions: (1) the eastern and central areas, (2) the western area and its northern extension.

I LITHOSTRATIGRAPHIC CORRELATION IN THE LADINIAN BASIN OF THE DOLOMITES

1. Lithostratigraphic correlations in the eastern area (Dolomites of Cadore)

a) Type-section in the Dolomites of southern Cadore (fig. 2A)

The Zoppe section (n° 1) shows 6 lithologic units of pelagic and tuffitic strata lying on the terrigenous-pelagic Upper Anisian sediments of the Ambata Formation. A first calcareous-dolomitic or siliceous pelagic unit of dark thinly bedded sediments is called, more conveniently, "Plattenkalk", banded limestone or flag-stone.

The second tuffitic unit is made of four green "pietra verde" sequences alternating with pelagic strata. Each sequence firstly includes a coarse tuffitic facies and then a fine pietra verde facies. The first sequence (14 m thick) is made of a lower coarse-grained part (2 m) and an upper fine-grained one (12 m); the second and main sequence (82 m), called the "main sequence", includes at first a tuffitic breccia with pelagic nodular elements and a tuffitic pumiceous lapilli facies; the upper part is made of 15 m of fine tuffite with radiolarians (cf. fig. 6 A). The third sequence (17 m) begins with 2 cm of coarse crystalline tuffite characterized by its great lateral estension; it shows the three other facies: 2.4 m of bedded vitric-crystal tuffite, 6.8 m of fine massive vitric tuffite and 6.5 m of very fine, bedded tuffite with a conchoidal break. The upper transition with the pelagic strata is marked by a 4.2 m thick succession of tuffitic cycles with graded bedding and a calcarenitic mixture or a coarse crystalline facies at its base. The finer tuffites of each cycle change into a pelagic nodular or banded limestone. The fourth sequence (19.5 m) comprises 1.1 m of coarse tuffite with pumiceous lapilli at its base and the succession of tuffitic facies already described, which includes 11.5 m of very fine tuffites rich in radiolarians.

Our knowledge of these sequences of the "lower pietra verde" (= LPV) ought to be completed by the systematic survey of the pelagic sediments, the paleogeographical interest of which is very important. The pelagic deposits at the base of the first sequence are of the Plattenkalk type and are called "lower Plattenkalk" (= LPK). But the nodular limestones are prominent between the sequences, both with the Plattenkalk (between the 1° and the 2° sequence) or alone elsewhere. These pelagic strata are called the "lower Knollenkalk" (= LKK).

The LPV is separated from the following tuffites by a homogenous grey nodular limestone unit, 24 m thick and containing only 2 tuffitic beds at its top. This nodular limestone called "median Knollenkalk" (= MKK) is of great and classic stratigraphical importance.

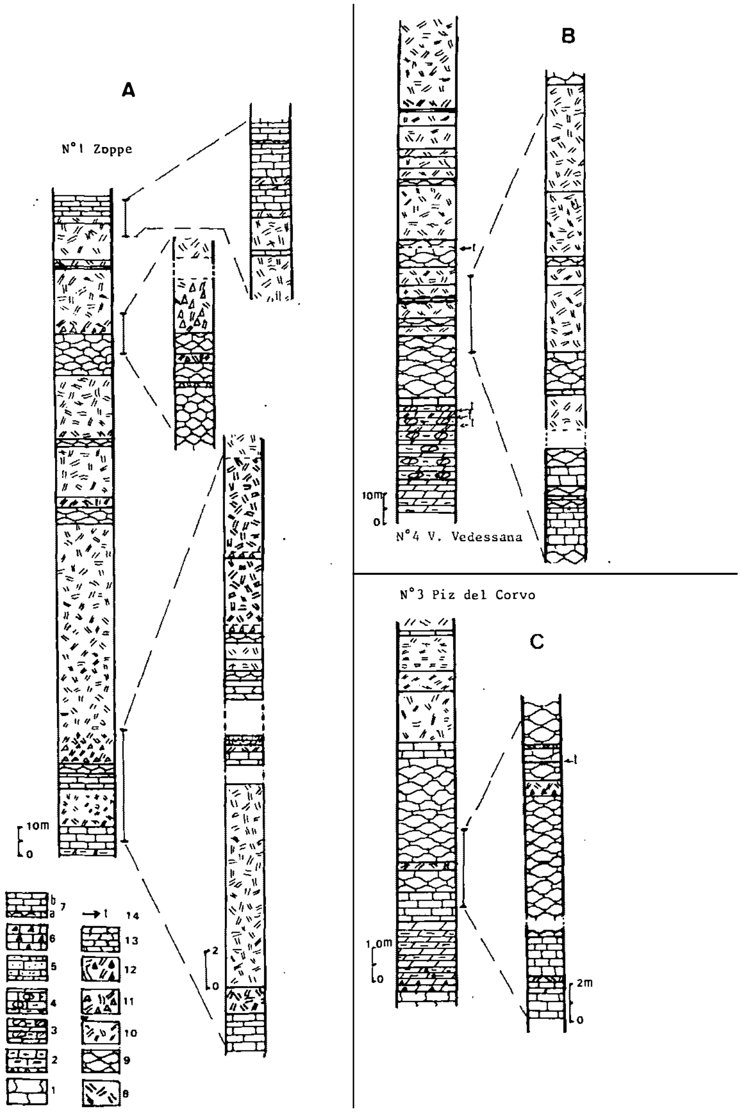


Fig. 2:

Livinallongo Formation, south-eastern area type sections. A: Zoppe (n° 1); B: Valle Vedessana (n° 4); C: Piz del Corvo (n° 3)
Symbols: 1: dolomitic or limestone biogenous platform facies (Contrin); 2: dolomitic or marly calcareous facies of Ambata type; 3: marly calcareous facies; 4: dolomitic facies of "Vedessana" type; 5: graded-bedded hemipelagic calcarenites; 6: calcareous microbreccias; 7: banded unbioturbated pelagic facies of Plattenkalk type (a) or coquina like (b); 8: coarse tuffites; 9: nodular limestones; 10: fine-grained tuffites; 11: tuffitic breccia with pelagic calcareous intraclasts; 12: polygenic tuffitic breccia with platform lithic elements; 13: partly bioturbated Plattenkalk.

The upper pietra verde (= UPV), 35 m thick, is formed first by 3 m of vitric-crystal-tuffitic breccia, with pelagic limestone intraklasts, then by a a succession of four cycles of graded-bedded pietra verde, with vitric-crystal facies, grading upward to a very fine radiolarian-rich tuffite. The thickness of the cycles is very irregular (21.5 m, 1.75 m, 15 m, 0.50 m). The last pelagic unit (7.5 m thick) is called upper Plattenkalk (= UPK) and separates the UPV from the overlying "Zoppe tuffites", belonging to the next terrigenous pelagic Upper Ladinian Aquatona Formation (VIEL, 1979; CROS, 1979).

In short, this sequential subdivision of the Livinallongo Formation points out the main proper characteristics of each tuffitic unit. So the LPV shows a parallel evolution between the thickness and the volumetric importance of the coarser tuffites. The same applies to the number of tuffitic cycles in the uppermost pelagic intercalations covering each sequence. From bottom to top the first and second tuffitic sequences show the quick increase in volcanogenic supply; the third sequence is marked by a sudden decrease in grain size; the last one is the result of a renewed increase in the coarser tuffitic supply, but much lower than for the second sequence.

b) Extension of lithologic units to the south-eastern part of the basin

The Col Alto section (n° 2) is situated near the Anisian calcareous Monte Rite (FARABEGOLI, PISA & OTT, 1977), 6 km eastward from the previous section. The LPK unit lies on the Ambata Formation, already containing some tuffitic beds. The LPV is made of the four sequences already described. The variations affect the granulometric sorting and the relative importance of the fine tuffites. The thickness relationships of the four sequences are those observed in the previous sections. The MKK is thinner (10 m); the UPV (40 m) is formed by a succession of graded bedded fine tuffitic cycles, with scarce pelagic interbeds. The UPK separates these tuffites from the overlying Zoppe Member.

c) Lithologic evolution in the eastern part of the basin

Its evolution follows two different courses:

Evolution towards the middle of the basin: role of the paleorelief (CROS, 1974, 1979) (fig. 2 C, 7)

The Livinallongo Formation outcropping at the eastern side of the Piz del Corvo (section n° 3) shows a typical thinning out of the prograding lithologic units at the flank of the Anisian paleorelief, a paleogeographic dependency of the southern Civetta platform (FOIS & GAETANI, 1980).

The section (Rio Sacuz, 2 km from the end of the bevelled series) begins with 24.4 m of the Ambata Formation. The Livinallongo Formation decreases in thickness, but keeps its proper order. The LPV is reduced to a few thin beds, the second one is a coarse metre-thick bed with a basal breccia in a coarse tuffitic matrix; the other ones are decimetre- to centimetre-thick and crystalline.

Correlatively the pelagic facies increase: the LPK is 8.5 m thick, the LKK is 7.5 m, the MKK is 35 m thick. The UPV is only fine-grained, massive

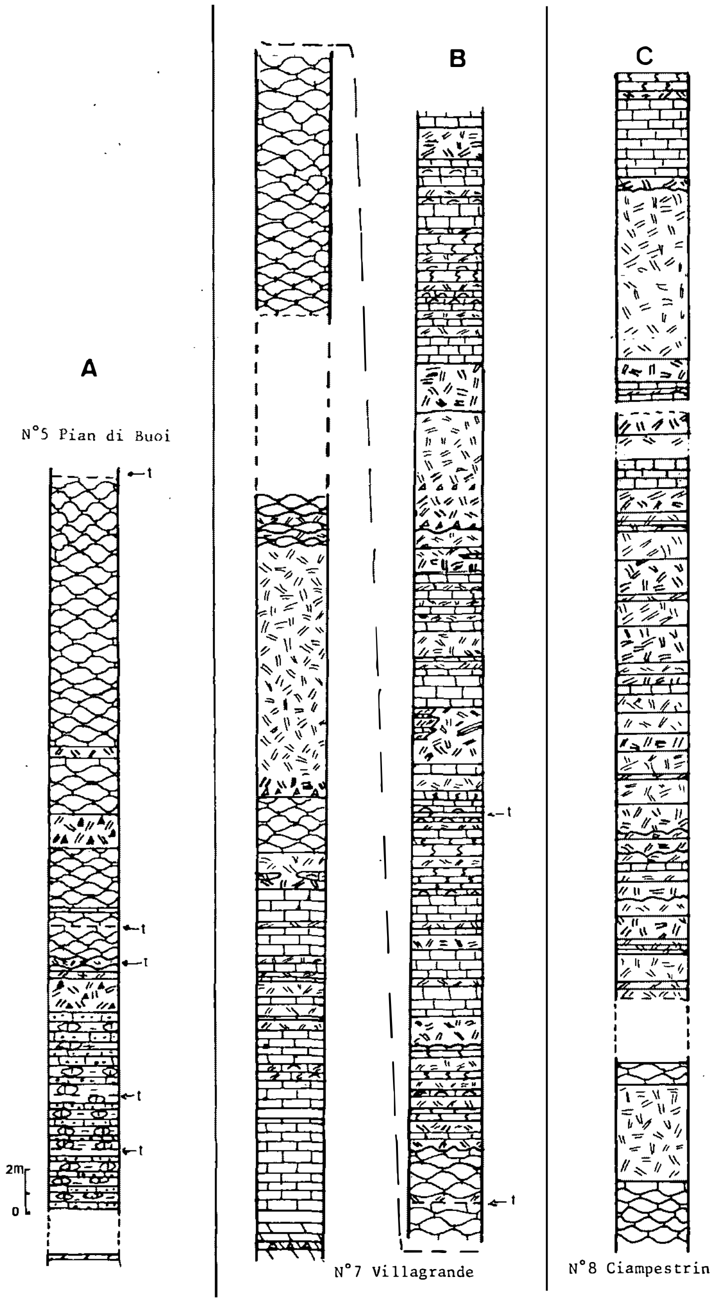


Fig. 3:

Livinallongo Formation. North-eastern (A) and central areas (B, C):
A: Pian di Buoi section (n° 5); B: Villagrande (n° 7); C: Ciampestrin (n° 8), upper part (UPV and UPK).

(40 m) and its upper part is bedded, covered by 6 m of UPK with tuffitic laminae. This UPV thins out towards the top 2 km westward, it is less than 10 m thick. This applies to the MKK. The modalities of facies change between these tuffites and the heteropical pelagic limestones at the contact with the upper part of the paleorelief have already been described (CROS, 1979, p. 960). It may be added that the eastern Cernera Summit: 2626 m, the highest visible part of the paleorelief, is eroded and affected by horizontal holes and clastic neptunian dikes filled with grey or read and tuffitic biomicrites, typical features of an Aniso-Ladinian discontinuity and deposit gap. This gap may replace the whole Livinallongo Formation; some remnants of the Zoppe tuffitic member are still visible on the eroded Anisian limestone of the Forcella Loschesuoi. This paleorelief could have played a role of a submarine discontinuous sill, dividing the eastern and the western part of the basin.

Evolution eastward: *role of the detrital supply*

The Vedessana Valley section (n° 4, fig. 2 B) has to be completed by some other adjacent partial sections; it begins on the Ambata Formation with 20 m of pelagic-tuffitic special alternating facies, called the "Vedessana Facies". They consist of regularly bedded or lenticular dolomitic limestones, clear of tuffites strongly bioturbated, and green dolomitic marls, coarsely tuffitic; this facies does not exist southwards. This lower unit is abruptly covered by 1.5 m of LPK. The LPV is thin, the first sequence is reduced to a few thin tuffitic beds at the top pf the Vedessana facies and to a small fraction of tuffitic input in the carbonate near-platform facies. The three other sequences are only some meters thick (3 m, 3.5 m, 5.5 m) with always a coarse crystal-tuffite at their base. On the other hand, the LKK unit is 18 m thick, MKK measures only 7 m upon the last beds of LPV. The three thick UPV sequences, sometimes complex and fine-grained, measure 17 m, 18.5 m and 55 m and alternate with meter-thick beds of nodular limestones forming the so-called "upper Knollenkalk" (UKK). The UPK unit is present at the top of the section.
The Pian di Buoi section (n° 5, Fig. 3 A), 6 km north- to north-eastward from the previous one, lies on the 40 m thick Ambata Formation and begins with 9 m of Vedessana Facies, exhibiting thin graded bedded calcarenites, resedimented from the adjacent platform; their frequence decreases topwards. This testifies the lateral facies change between the shallow platform area outcropping in the region of Col Vidal (OGILVIE GORDON, 1934) and the pelagic basin. The LPV is represented only by two crystal-pumiceous tuffitic sequences also containing various lithic elements reworked from diverse lavas. The first sequence begins with a tuffitic limestone breccia the components of which are of platform and pelagic origin; they are associated with angular volcanic lithic elements. This lithologic character is remarkable and testifies the role of another pyroclastic and epiclastic supply; its paleogeographical origin may be found in the south of the Carnic Alps (cf. CROS, 1979). The resedimented platform bioclasts of the 6 m thick hemipelagic facies separating the tuffitic strata are of Vedessana type; the MKK (13 m) still contains some graded-bedded calcarenites and tuffites. The top of the section does not outcrop, but no traces of the UPV were found in the area under the basic tuffites of the Fernazza Formation.

Evolution northward: disappearance of the tuffitic supply near the north-eastern boundary (fig. 4 B)

The eastern Dolomits exhibit, 12 km north of the Vedessana Valley section and 28 km from the Zoppe section, the whole Livinallongo Formation, which is thin and essentially of pelagic character (section 6 near San Marco, outcrops near Stabin and Lago Verde).

A few meters of the Vedessana type bedded or subnodular facies underlie (section n° 6) nearly 10 m of alternating "Knollenkalk" and tuffites of the LPV, forming 5-6 beds, decimeter-to meter-thick, like the nodular limstone intercalations. The MKK (30 m) is covered by 4 m of dark siliceous flagstone, with tuffitic laminae (UPK) hidden at their top.
The nearby section of Stabin shows eastward a maximal reduction of the LPV tuffites. The tuffitic Vedessana facies is 2 m thick and the LKK outcropping above (4.5 m) contains only few green argillitic tuffitic beds: the only indications of the LPV supply.

d) Conclusive remarks on the sedimentary evolution in the eastern area

The correlative variations of the pelagic and tuffitic sedimentation appear with three modalities.

The pelagic facies adjacent to the platform, characterized by a mixture of calcarenitic material, points out the role played by the heteropical boundary in the eastern region of Col Vidal, Auronzo and Dobbiaco. This bottom uplift favoured the thinning of the tuffites and the bioclastic supply is stratigraphically associated with the strongly bioturbated pelagic sediments.
The role of the Anisian paleorelief (Piz del Corvo, Eastern Cernera) inside the basin is most significant; the bevel of the tuffitic units is much better marked for the lower unit than for the upper one; the paleorelief effect was attenuated in the course of time and is different with each type of volcanoclastic marine environment. The strict investigation of the thinnest tuffitic beds allows a more precise correlation of the reduced deposit bevel with the thicker southern proximal units. Finally the tuffites may disappear 30 km north of the proximal accumulations (sections 1 and 2), without any other active heteropical sedimentation, There the depositional rate was very low.

2. Lithostratigraphical correlations in the western area (High Livinallongo Valley, Badia Valley; fig. 3, 4 A, B)

a) Sequential modalities of the tuffitic deposition

The detailed section of Villagrande (fig. 3 B, SS 251 road, km 153-154) is known very well (BACELLE & SACERDOTI, 1965); it is used here for the detailed correlations of all the disconnected outcrops of the Livinallongo Valley and for the unterstanding of the sedimentological westward evolution of the main tuffitic units. At the base of the section, the Contrin Formation is dolomitic and of irregular thickness, in continuity with the Cernera mount; it underlies the first basinal carbonate unit made of the calcarenitic microbreccias alternating with a euxinic, dolomitic Plattenkalk (3 m), which goes up to a dolomitic and then siliceous PK unit (8 m), partly tuffitic and

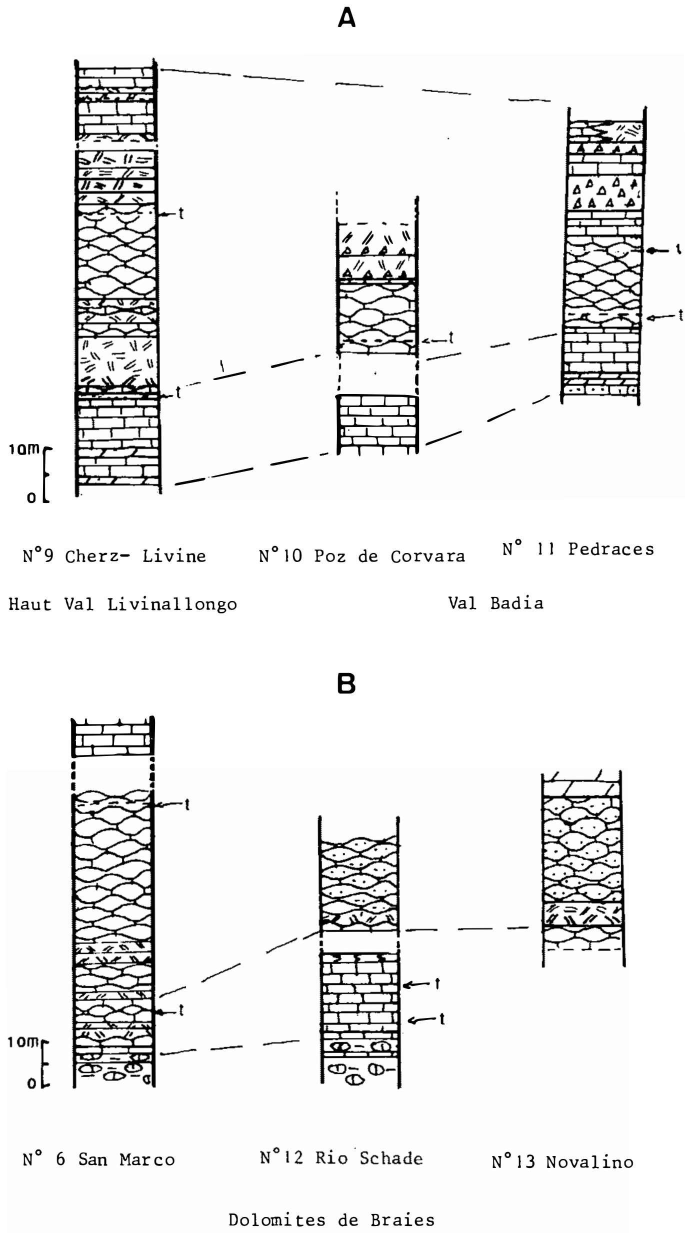


Fig. 4:

Livinallongo Formation. North-western (A) and north-eastern areas (B).
A: High Livinallongo and Badia Valleys; Cherz-Livine section (n° 9); Poz de Corvara (n° 10); Pedraces (n° 11). B: Dolomites of Braies: San Marco (n° 6); Rio Schade (n° 12); Novalino (n° 13). t: tuffitic thin beds or cineritic green clay.

sometimes coquina-like with *Daonella*. The first LPV coarse-grained strata (1.5 m), then fine-grained (0.8 m) with thin nodular limestone-intercalations, is followed by a 2.5 m thick LKK with green clay seams. The main tuffitic sequence is 11.5 m thick and begins with a pelagic calcareous tuffitic breccia; it is coarse-grained and overlain by 3.2 m of alternating graded-bedded pietra verde and nodular limestone. The MKK unit is 20 m thick.
The UPV begins with 2 m thick beds of coarse crystal-tuffite alternating with some meters (6 and 8 m) thick banks of UPK containing tuffitic beds of coarse or fine texture. These beds are often hydroplastically deformed or broken by an intrastatal sndiagenetic fracturation. These arhythmic sequences of first and second order result from the turbiditic reworking of tuffitic material inside the pelagic basin. The coarse fraction is more developed than in the southern area, but that does not change the regional correlation of the UPV unit. The next section of Ciampestrin (n° 8, fig. 3 C) along the Rio Codalunga supplements the previous one; the UPV tuffites are thicker (60 m); more than ten sequences are graded-bedded with also abrupt superpositions of the coarse and the fine facies; they show a radiolarian-rich upper part; the pelagic Plattenkalk interbeds are scarce, the UPK consists of a 15 m thick unit with only one tuffitic bed.

b) Extension of the tuffitic sequences in the middle and western parts of the studied area (Cordevole High Valley; fig. 8 C)

The study of all outcrops disseminated on the northern and southern flanks of this narrow and deep valley confirms the general value of the six lithologic units already defined.

Sections with a strong pietra verde content

The LPK lies on the Anisian dolomite; the four sequences of the LPV are separated by nodular beds (LKK). The main sequence has a constant thickness (11 m) and facies; that is to say: a crystal tuffite (0.5 m) followed by the fine tuffites. The MKK are thick (20-25 m); on the other hand the sequential variations affect the UPV (fig. 8 C).
These tuffites cover directly the MKK unit or include at their lower level more UPK. The graded-bedding and the pelagic levels are either like the Ciampestrin section or the Villagrande one.
The paleogeographical disposition of the two sequential types defines a deeper area of main channelling supply and a lateral area of discontinous tuffitic dispersion and pelagic sedimentation.

Sections showing the bevelled pietra verde

The main sequence of the LPV is isopachous (11 m) and exhibits few variations, except for the boundary to the Lower Ladinian Marmolada platform facies, where it is thin and shows a mixture of bioclastic resedimented calcarenites: On the other hand, the UPV unit already gets thinner, but with both coarse and fine textures, it may be partially replaced by 19 m of pelagic UPK (Collaz section) or dissapears completely (Col Dadaut section): the MKK being covered directly by the pelagic UPK.

The southern border of the basin is marked by a quick facies change, first by the heteropical transition to the platform during the LPV and MKK,

and then by a synsedimentary tectonic deformation during the UPK and UPV stage of sedimentation. This discontinuous relationship between the uplifted parts of the carbonate platform and the adjacent area of breakdown affects the previous heteropical transition. It is marked by the slumping of coarse breccias with metric blocks of carbonate platform facies between the UPK pelagic strata of the Col Toront section.
We know (CROS, 1974) that this breakdown in horst and graben areas is achieved during the Upper Ladinian; it resulted in the paleorelief emersion, the karstification of part of the Marmolada mountain and the deepening of the bordering areas during the Fernazza stage of volcanic activity and basinal deposition.

c) Extension of the tuffitic sequences in the north of the western area (Badia Valley, Braies Dolomites; fig. 4)

Only two outcrops exhibit tuffitic beds, their extension is limited by the nearby Ladinian carbonate platform or Anisian paleoreliefs created by the previous Aniso-Ladinian tectonic stage (Passo Gardena: unpublished data, Sella?, north-western Marmolada; CROS, 1976).

Val Badia section (fig. 4 A, Pedraces, Poz de Corvara)

The Anisian "Braies" facies (= Pragser Schichten; PIA, 1937), equivalent to the Ambata Formation, is covered by a bioclastic hemipelagic deposit, first of LPK type, very poor in tuffitic content (11 m), then of KK type with resedimented platform bioclasts. Its total thickness (16.5-22.5 m) may be divided into two parts by a level of green tuffitic clay beds coming from and correlated with the main eruptive events during the LPV deposition (see below). Some polymictic breccias (1-10 m thick) consist of platform carbonate, pelagic and pietra verde lithoclasts, their occurrence is caused by the intraformational tectonic and gravitational reworking preceeding the UPV deposition and resedimented in the UPK basinal stage.

Braies Dolomites section (fig. 4 B, Rio Schade, Novalino)

The pelagic LPK (13.5 m) covers a Vedessana type facies; it contains tuffitic laminae; the LKK (1-3.5 m), massive or bedded, is separated from the MKK (14-17 m) by green clay seams and only one sequence of LPV (1-5.5 m thick with 30 cm of coarse tuffitic facies). The MKK contains resedimented bioclastic calcarenites. The Upper Ladinian dolomite covers this thin Livinallongo Formation. This well-known reduction is complemented by the early replacement of the platform sedimentation.
The new correlations are supported by the occurrence of tuffitic green clays and the relative disposition and thicknesses of the LKK and the MKK and the pietra verde. We may conclude that:
- in the north-western area the LPV, constant in the south, has dissapeared and has been replaced by tuffitic clay beds; on the other hand, the UPV associated with breccias may be 13 m thick and includes coarse facies southwards and finer ones northwards.
In the poorly tuffitic north-eastern area we notice only the occurrences of the LPV with both cineritic clay facies and coarse turbiditic facies.

II PALEOGEOGRAPHY AND SEDIMENTOLOGY OF THE VOLCANOGENIC SERIES

1. Paleogeographical distribution of the volcanogenic sediments

a) Evolution stages of the volcanic centre's activity

The famous pietra verde (CALLEGARI & MONESE, 1964) results from the hydrodynamic transport and reworking phases of pyroclastic particles in the quiet pelagic basin. They are accumulated in the deeper parts, but the facies and thickness changes are also caused by the volcanic centre's localization. These were many times supposed to have a southward origin. The petrographic analysis supports the definition of some new paleogeographical ways. The succession of the two eruptive phases and of the intermediary quiet periode is of regional importance. In fact, the mineralogical characters of the tuffites are those described by CALLEGARI & MONESE (1964), but some specific features were observed in each unit; we shall summarize them here soon (HOUEL, 1979)

The whole mineralogical and chemical data related to the feldspars and quartz and their inclusions suggest that the pyroclastic material from the LPV is of trachy-andesitic composition; for the UPV the composition is rhyodacitic to rhyolitic. Nevertheless the UPV also shows more basic plagioclases than the LPV, mainly in its upper part, but it is alone to contain up to 10% and 20% of rhyolitic quartz, supposed to be of pyroclastic origin, mainly in its lower part; this quartz is also present in the ignimbritic lithic elements reworked into a lenticular conglomeratic tuffitic and terrigenous facies, at the base of the UPV; this coarse bed has already been described on the paleorelief (eastern flank of the Piz del Corvo; CROS, 1979). Finally the tuffites contain some biotite, the main ferro-magnesian silicate; the UPV contains some green amphibole (less than 1%), intact or replaced by sparite and anatase.

Repartition and origin of the lower pietra verde sequences (fig. 5, 8 A)

Sequences like the main sequence of the LPV occur in the axial part of the basin and are bevelled sidewards and northwards, with special modalities for each type of submarine basinal bottom features.

In the basin axis the main sequence changes from a 80 m thick sequence in the Zoppe section to 11 m in the Livinallongo Valley district, that is to say 16 km north-westwards but then it keeps this 11 m -thickness. Northwards the LPV is mixed with pelagic sediments, but is still coarse-grained; finally it is reduced to some argillaceous green beds of subaerial cineritic origin with a mixture of hydrodynamically deposited plagioclase crystals.

The metric strata of crystal-lithic tuffites observed in the north-eastern sections (Pian di Buoi, San Marco) are characterized by a group of various volcanic lithic elements which are oxidized and sometimes rounded. Such tuffites have already been described in the western Carnic Alps (Monte Rigoladis section; CROS, 1979). They also occur at the base of the LPV, in the northern Sappada section. The south-eastern origin of the LPV sequence is different from the first type sequence with which it is mixed in the eastern Dolomites.

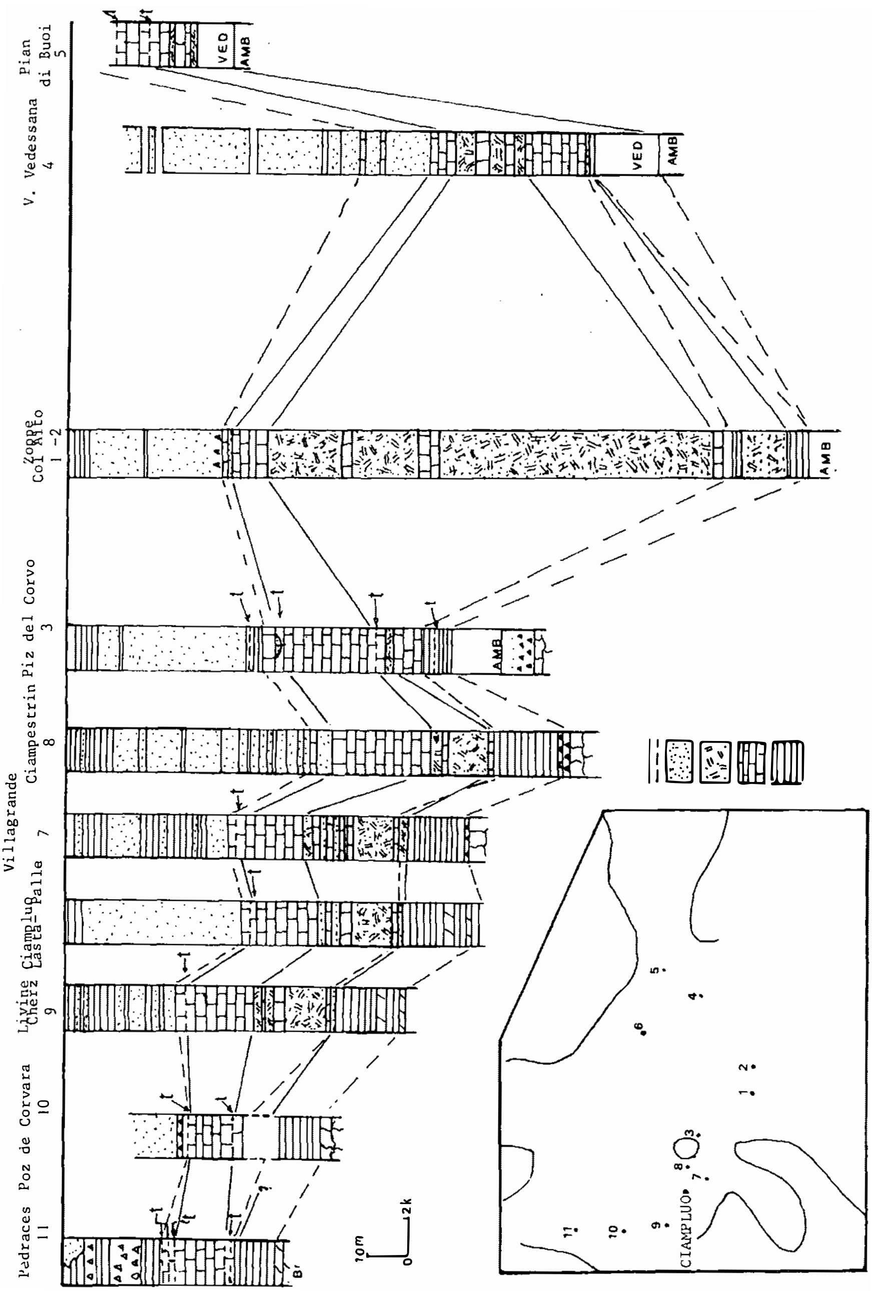


Fig. 5: Lithologic correlations in the Livinallongo pelagic and tuffitic basin. The sections are lined up on the basis of the summital terrigenous and pelagic Aquatona Formation; especially the Zoppe Member.
The continuous correlation lines point out the boundaries of the tuffitic units. The dashed lines point out the biofacies boundaries.
Symbols: 1: Plattenkalk; 2: nodular limestones (Knollenkalk); 3: lower pietra verde; 4: upper pietra verde.

Repartition and origin of the upper pietra verde sequences

The successive tuffitic sequences are 0.3-10 m thick, with an average of 2 m (fig. 8 B).

The coarse and fine-grained tuffites display a distinct paleogeographical extension. The coarse material occurs essentially in the western part of the basin, mainly in the south-western part, between the Passo Gardena paleo-relief to the north-west, the marmolada to the south-west and the Piz del Corvo paleorelief to the south-east (fig. 8 B). The fine material is present in the whole western basin area, in the same quantity as the coarse one; it is dominant in the south, reduced to the north. The fine tuffitic facies itself occurs in the southern and eastern areas, except for some scarce thin beds.

We may add the disappearance of the UPV in the north-eastern sections, though eastwards there is another tuffitic deposit centre in the Carnic Alps (LAGNY, 1974). This repartition is controlled by the volcanic activity of an eruptive centre along the southern boundary of the basin, the pyroclastic supply of which had been accumulated in the southern Cadore and the nearby Carnic Alps. The hydrodynamic dispersion around this centre had been effective along two syngenetic transverse tectonic troughs separated by paleoreliefs as the Piz del Corvo westwards, and the Tiarfin mount eastwards (cf. fig. 8 B).

A second subsidiary origin had occured around a northeastern volcanic centre marked by a coarse tuffitic supply during the upper pietra verde stage.

b) Role of the carbonate shallow bottoms in the pelagic basin: the case of the Cernera - Piz del Corvo positive area (fig. 7)

The carbonate mountains of the Monte Crot and the Cernera - Piz del Corvo have played a complex paleogeographical role in the differential occurrence of the two pietra verde units. They are situated north of the Civetta platform (FOIS & GAETANI, 1980) with which they were connected in the Anisian time.

The detailed analysis of the relationship between the biogenous carbonate facies in the northern part of the Cernera mount and the adjacent Livinallongo pelagic and tuffitic sequences supports the heteropical restauration of this area along the western side of the positive submarine Cernera - Piz del Corvo paleorelief. The carbonate foothill, called Punta di Zonia, is the north-western continuation of the upper biogenous limestones of the Cernera mount. This formation is not accurately dated in the Cernera mount istself, but it is bevelled westwards under the basic Upper Ladinian tuffites of the Fernazza Formation, outcropping westwards on the southern flank of the Monte Pore (fig. 7 A). From east to west, this carbonate tongue of platform facies changes laterally to a bioclastic and biogenous bedded limestone with *Tubiphytes* etc. ... The bevelled end of this outcrop shows exceptionally two successive fossiliferous levels with ammonites (fig. 7 B). The first one is an unsorted brachiopods-lamellibranchs-crinoidal phosphatized biosparite with ammonites of the Aploceras avisianus zone (*Aploceras avisianus* (MOJS.), *Proarcestes pannonicus, Ceratites hungaricus* (MOJS.), determinated by R. ASSERETO); this bed locally marks the avisianus-reitzi zone, usually placed either at the top of the Illyrian substage (ZAPFE, 1974) or at the base of the Fassanian (KOZUR, 1974; BALOGH, 1981). The second fossiliferous level is a biomicrite with ammonites of the curionii zone (*Protrachy-*

ceras cf. *recubarense* (MOJS.), *Pr.* cf. *gortani* PISA, *Megaphyllites* cf. *jarbas* (MUNSTER), *Sagoceras* cf. *walteri* MOJS., *Epigymnites melleri* (MOJS.), *Monophyllites* cf. *wengenensis* (KLIPSTEIN), *Sturia semiradiata* MOJS., *Ptychites* cf. *ulhigi* MOJS.,determinated by H. RIEBER). These strata are therefore passing laterally to the basin facies, they contain two thin tuffitic beds on both bottom and top of the median subnodular limestone. The upward pinch along this lateral facies change is hidden by scree. It is likely that both the LKK and the MKK units grade laterally to the fossiliferous facies. Therefore, the upper carbonate strata building the top of the Cernera mount and its western foothill (Pian di Passaliou) with *Diplopora annulata* and associated tidal facies had been developed above the Aniso-Ladinian, here "blended", discontinuity surface; it is well preserved in the Piz del Corvo area, but may only be conceived in this western part (fig. 7 C) because of this local Ladinian carbonate overlap.

This complex paleorelief hindered the tuffitic supply coming from the south, but was still an active biogenous area on the opposite side, during part of the Livinallongo Formation. This paleogeographical change explains the various thicknesses and decreasing modalities of the tuffitic sequences.

Finally, in spite of the lack of outcrops, we believe that a row of complex paleoreliefs formed a paleogeographical sill between the Civetta southern area and the Piz da Peres northern area, dividing the basin into two parts. This would explain the occurrence of some resedimented calcarenites in the MKK of the Cherz an Andraz region (high Livinallongo Valley) and of the Poz de Corvara (high Badia Valley) areas (fig. 8).

It is also suggested that this transverse paleostructure is also the source of supply for the breccias and limestone blocks embedded in the Fernazza ·strome and accumulated on the northern side of the Valley (Varda, Monte Sief) during the Upper Ladinian platform breakdown. All these outcrops lie far away from any other possible sources (CROS, 1974).

This working hypothesis may also explain the occurrence of the LPV only eastward and the UPV sequences only westward in the northern part of the basin (fig. 4).

2. Sedimentology of the volcanogenic series

a) The pyroturbidites of the "lower pietra verde" (LPV)

The submarine pyroclastic flows (subaqueous pyroclastic flows of FISKE, 1963)

The author has given a petrographical and sequential definition of the submarine pyroclastic flows still considered as a useful pattern and methodological reference. Here the so-called pyroturbidites are large accumulations of many tuffitic sequences made of non-welded particles, pumiceous and fine breccias (3-60 m thick). They alternate with ordinary turbidites and cineritic "ash-fall" deposits. FISKE (1963) defined three types dependent on the relative content of diverse lithic elements, of angular pumiceous elements, and of acid glass chards. The composition and facies changes support the eruptive event interpretation; a pyroturbiditic succession helps to define a volcanic stage. According to the kind of flow, the volcanogenic dynamics may be related to three contrasting types of underwater eruptions coming from either a powerful phreatic eruption or an eruption of vesiculating magma; finally it may be an explosive desintegration of a homogenous body of lavas, such as a dome, or lava flows entering water. The remnants of submarine volcanoes may be detected by the coarsest breccias.

We shall use the name pyroturbidite in a descriptive way for a thick volcanoclastic sequence with a coarse or breccious base and graded-bedded structure. Its compositions shows vertical facies changes. From a genetic point of view, our pyroturbidite was born during a submarine or a subaerial eruptive event in a marine environment.

The main characters of a pyroturbidite evolve and are interpreted by a combination of the volcanic dynamism and the basinal hydrodynamism, resulting from the relative paleogeographical disposition of the volcanic centre and of the final deposit-centre.

Examples of pyroturbidites (the main sequence of the lower pietra verde)

The LPV main sequence consists of a basal intraformational breccia, a coarse crystal-tuffitic banded lower part (fig. 6 A), a thick vitric cineritic fine tuffite with typical chards of acid vesiculated glass (HEIKEN, 1972) and, finally, a very fine radiolarian-rich tuffite, the top of which exhibits ripples and convoluted laminations.

The supply must have been rapid and characterizes the deeper parts of the basin away from the volcanic centre. This pyroturbiditic sequence, mainly of vitroclastic character, is followed by microsequences of pelagic-tuffitic composition with a crystal-rich tuffitic basis and graded-bedding. These beds may be bioturbated or bioclastic; their upper half is banded and pelagic.

Taking into account the pyroturbiditic evolution and the huge volume (more than one cubic kilometre for the main sequence) of pyroclastic material, we think that it resulted from one important eruption.

The impossibility of detecting its position inside the outcropping Ladinian basinal deposits leads to placing the volcanic centre nearer to the south but outside the Dolomites.

The submarine transport along the pelagic basins' slopes by density currents caused the pyroturbidite; the following reworking fo the top of the sequence mixed with subaerial cineritic supply fallen down in the basin and on the nearby platforms, caused the microsequences.

Various pyroturbidite types occurring in the Livinallongo Formation (Dolomites and Carnic Alps)

Apart from the crystal-vitric pyroturbidite from Cadore we found another type of sequence in the western Carnic Alps; it is characterized by the frequency of both altered and non-altered lithic elements in the whole succession. This pyroturbidite, already mentioned above, forms a 23 m thick unit, corresponding to the LPV lithostratigraphic unit. At its base it shows 5 m of breccious conglomeratic tuffite made up of platform limestone elements, overcrowding a few pelagic and various volcanic lithic elements, such as acid and intermediate lavas, with glassy or microlithic textures; some have an ignimbritic character. The second very coarse facies is roughly bedded and more or less cemented, probably in relation to the different frequency of the squeezed and altered pumiceous lapilli; it is rich in lithic elements

(15 m). The third facies is a 3 m thick crystal and fine tuffitic pietra verde.

This sequence has a more proximal character than the first one, but it is still deposited in a pelagic trough between two paleoreliefs as shown by the overlying MKK (13 m thick). The sequence is thinner northward in the Sappada area and is divided into two subsequences enriched in crystal-vitric pietra verde. The metre-thick beds of LPV from the north-eastern Cadore are analogous but finer; they constitute a distal outcrop of this special pyro-turbiditic supply.

The supposed volcanic centre had to be very near in a southward direction; the volcanic environment was different both in paleogeographical position (subaerial to littoral) and pyroclastic to lavic composition.

A third type of sequence has already been described in the central Carnic Alps, in the Dierico trough, between Paularo und Tolmezzo (Prov. of Udine; CROS & FRYSSALAKIS, 1982). This pyroturbidite, unknown in the Dolomites, is made up of a very coarse conglomeratic breccia (3 m) with platform limestone elements and various acid and basic (spilitic lavas) or ignimbritic elements. These latter volcanic elements are frequent in the forth-coming breccia (5 m). The sequence is then formed mainly by a 30 m thick, very coarse dark green tuffite, either of pumiceous lapilli or of mixed pumiceous-crystal facies. The top of the sequence is made up by the classical, already described, medium to very fine pietra verde facies.

The pelagic deposits of "Plattenkalk" type cover this sequence. The nature of the lithic elements, the frequency of pumiceous lapilli and the occurrence of ignimbritic elements throughout the coarse facies point out the explosive phreatic and subaerial activity of the eruptive centre. It was complex and situated along a northern, emerged basement ridge.

In all these examples, the pyroturbidites may be interpreted in paleogeo-graphical and volcanological terms. If we take into account the relative distance of the centre, the sea-bottom irregularities, the sequences should be formed by more or less coarse of fine pyroclastic material, enriched in diverse types of particles. Each pyroturbidite defined in the paleogeographical framework suggests the precise conditions of an important eruptive event. Laterally it is replaced by a classical turbidite, if the reworking conditions were domi-nating against the pyroclastic accumulation. These reworking conditions are the driving forces in the distal and shallower areas of the basin. Finally the replacement in the pelagic realm of the pyroturbidites and derived turbidites by the subaerially transported cineritic beds, often heavily bentonitized, complements our knowledge of the basin bottom topography and the eruption chronology very well.

The interpretation of the two pyroturbidites found in the Dolomites may be summarized as follows: The first type suggests a very strong explosive eruption-phase, mainly subaerial but forming a thick pyroclastic sheet sur-rounding continuously the centre and situated mainly or totally in the marine environment.

The second type may characterize the volcanic lava effusion and then the pyroclastic explosion and explain the occurrence of ignimbrites and abundant ash-fall sedimentation; that suggests the subaerial activity of an emerged centre in a platform environment. These two different centres seem to be synchronous and situated on the same southern volcanogenic ridge though not at the same distance from the actual outcrops.

b) The turbidites of the upper pietra verde (fig. 6 B)

These UPV sequences result from a second volcanogenic stage and cannot be the mere reworking of an older pyroclastic deposit. Their stratigraphical repartition and volume, the occurrence of various levels of accretionnary lapilli suggest a succession of minor eruptive events. The turbiditic character of the sequences in the Villagrande section were recognized many years ago (BASELLE & SACERDOTI, 1965). It is less evident for the sequences of the Ciampestrin section.

Nevertheless it is still visible by a precise sequential analysis. In the latter section the sequences, 0,3-10 m thick with an average of 2 m, show a basal coarse facies and an upper fine facies with frequent granulometric breaks between them. The pelagic interbeds are scarce and thin. These sequences were laid down by a channel deposition, supplying the tuffitic sedimentation of the whole narrow basin, then accumulated in its deeper parts. At the same time the pelagic-tuffitic alternations of Villagrande type are made of coarse crystal-tuffitic material, discontinuously deposited in a lateral area near the previous channel.

The occurrence of coarse conglomeratic channel deposits, isolated on the Piz del Corvo paleorelief-flank suggests the possibility and proximity of a molasse-like traction transport near the shallower marine turbulent range around this submarine discontinuous paleorelief or sill.

The reconstruction of the volcanic dynamics and magmatism linked to the turbiditic pyroclastic deposition of the UPV is more difficult because of the better fractionation of the pyroclastic supply during transport. The numerous sequences alternate in varying manner depending on the bottom morphology. Then two divergent supply centres seem to have mixed their material. We suppose the first and main centre to be southward, out of the pelagic basin and associated with a basement ridge, delivering a terrigenous synchronous supply. It seems to have furnished mainly fine material suggesting some distances from the centre to the Zoppe area. On the other hand the north-western subsidiary centre explains the coarse tuffitic supply mixed with the fine one; it may be nearer.

Finally, as supposed by FISKE (1963), many small eruptive events extending for a long time followed by intrabasinal reworking may explain the sequential disposition.

Nevertheless, the petrographical analysis of the crystals and lithic elements allow some detailed definition. The occurrence of acid lavas and ignimbritic lithic elements mixed with fine pyroclastic particles indicates the subaerial way of eruption before reworking. The same applies for the lenticular pumiceous lapilli facies. The pyroclastic activity of the two previous centres continued during the Upper Ladinian deposition of the Zoppe tuffitic member.

The latter terrigenous tuffitic sequences show an epiclastic coarse facies south of the Dolomites; they are fine and of limited extension with a more pyroclastic character in the central Livinallongo Valley; they are again coarse-grained and of epiclastic terrigenous nature in the northern Val Badia (Pedraces). This Upper Ladinian evolution testifies the tectonic and eruptive evolution of a southern volcanogenic basement ridge (CROS, 1979). We ought to point out now the role of a northern ridge which gives evidence of the complex Ladinian paleogeography (CROS, 1982).

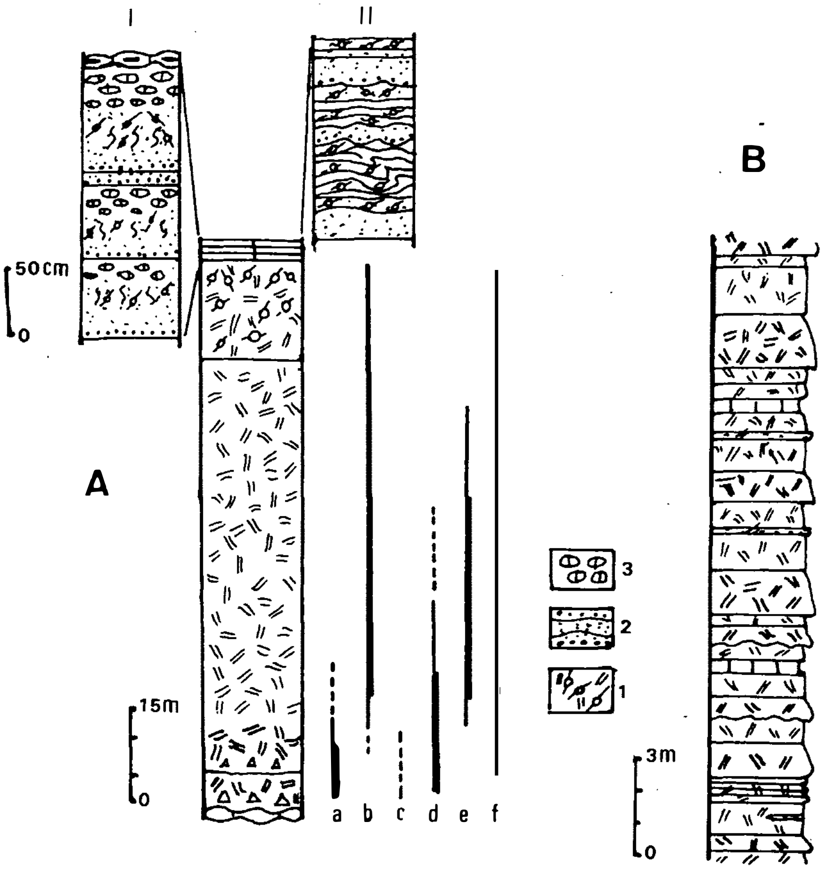


Fig. 6:

Sequential composition of the pietra verde tuffitic units. A: second "main sequence" of the LPV as a pyroturbidite type (Zoppe section). Diagramme: a: lapilli and coarse vitric tephra; b: fine ashes; c: volcanic lithic elements; d: crystals; e: glass chards; f: matrice. B: turbidites of the UPV (Ciampestrin section).
Symbols: 1: very fine pietra verde with radiolarians; 2: graded microcycles; 3: calcareous nodules.

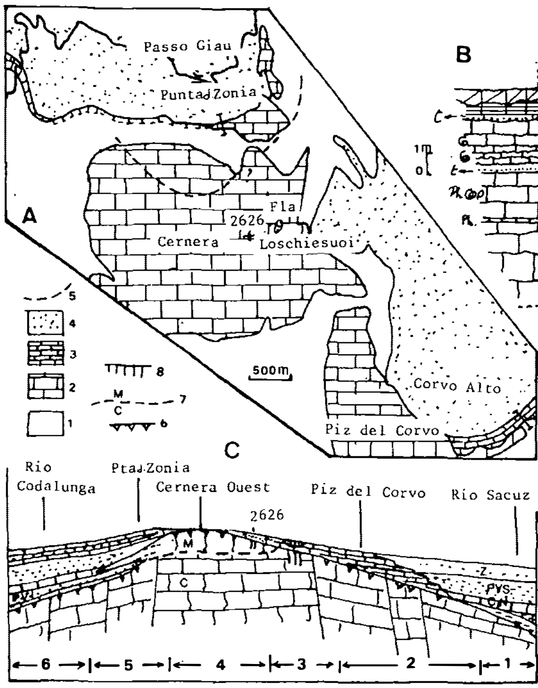


Fig. 7:

Complicated paleorelief structure of the Cernera - Piz del Corvo massive.
A: localization and lithologic sketch.
Symbols: 1: scree and unstudied formation; 2: carbonate biogenous platform facies of Anisian and Ladinian age (beside the dashed line corresponding to the supposed boundary between the two isopic formations on either side of a hidden discontinuity); 3: Livinallongo Formation; 4: acid tuffites of the Zoppe Member and Wengen basic tuffites; 5: supposed Ladinian carbonate boundary; 6: subaerial erosional discontinuity; 7: Anisian-Ladinian carbonate superposition (C: Contrin Formation, M: Marmolada Formation); 8: clastic dykes in Anisian carbonates.
B: fossiliferous section of the Punta di Zonia foothill at the end of the heteropic tongue of the platform slope sequence passing to the basin deposits.
Facies of the strata: 1: dolomitic limestone, supposed to be of Anisian age and of typical platform facies; 2: phosphatized dark bioclastic limestone (10 cm); 3: fine bioclastic limestone (1 m); 4: coquina-phosphatized biosparite with ammonites of the avisianus zone (0.8 m); 5: grey limestone going from biosparite to biomicrite; 6: thin, green tuffitic level; 7 and 8: grey, subnodular micritic limestones with ammonites of the curionii zone (7: 1.3 m and an upper fossiliferous bed, 8: of 0.2 m), covered by a micritic facies (0.9 m); 9: second thin tuffitic level covered by a Plattenkalk-like banded facies, upper part dolomitized.
C: schematic cross-section of the complex paleorelief before the Zoppe Member tuffitic deposition. 1: transgressive onlap of the Livinallongo Formation; 2: lithologic bevelling of the tuffitic units and transition to the onlapping units; 3: discontinuity surface with clastic dykes covered by the Zoppe Member; 4: Lower Ladinian heteropic superposition above the Anisian dolomite ("hidden discontinuity"); 5: heteropic changes from the Lower Ladinian platform slope to the Livinallongo basinal sequences; 6: basinal sequences from Ciampestrin.

III PALEOGEOGRAPHY AND SEDIMENTOLOGY OF THE PELAGIC CALCAREOUS SERIES

1. Lateral facies change, meaning of the calcareous facies

a) Review of the various bathymetric interpretations of the pelagic facies

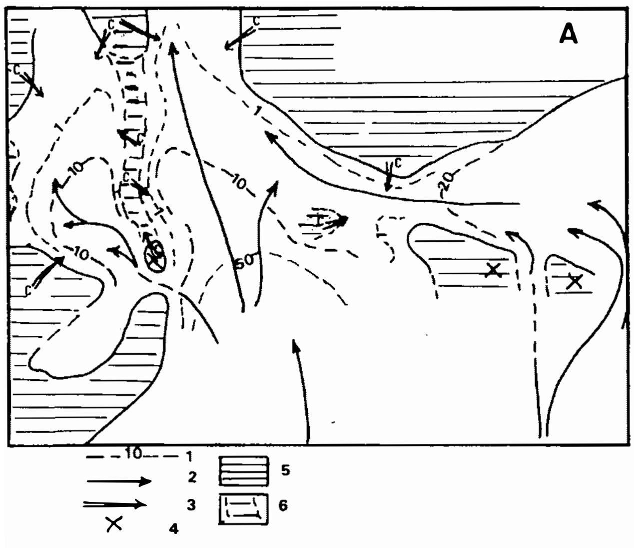
The bathymetrical interpretation of the heteropical relations between biogenous platform facies and pelagic basin facies is quite different among geologists. Some favour the deep marine model (BOSELLINI & ROSSI, 1974; GAETANI et al., 1981), others support the shallow marine model (CROS, 1974).

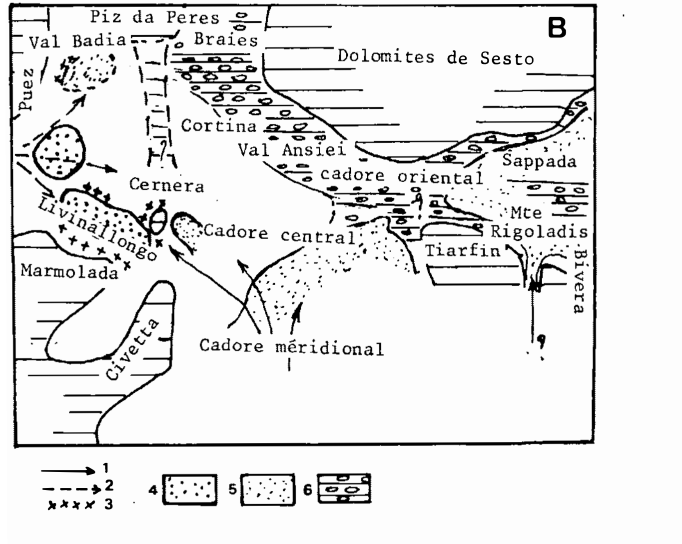
An answer may be found by the analysis of pelagic sediments. Recent studies of Aniso-Ladinian deposits (BECHSTÄDT & MOSTLER, 1974, 1976; BECHSTÄDT et al., 1976, 1978) taking into account the micropaleontological content, have proposed a bathymetric evolution from 100 m in the Upper Anisian time to more than 500 m in the Lower Ladinian. On the contrary, jointed facies and microfaunal analysis of the heteropical carbonate platform and adjacent basin deposits of Upper Triassic age (HOHENEGGER & LOBITZER, 1971; LOBITZER, 1975), for instance, have favoured a shallow, perhaps 70 m deep, environment for the transitional bioturbated pelagic facies. ZORN (1970) has proposed a shallow marine origin for the laminated, non-bioturbated, euxinic facies of the Middle Triassic of Lombardy, but the author points out that this might not be the same for the pelagic facies of the Dolomites owing to the steep slopes of the Ladinian reefs.

The bathymetric interpretation especially given about the red nodular limestones with ammonites of Hallstatt type is marked by the same divergent opinions (see BERNOULLI & JENKYNS, 1974).

b) Role of the bioturbation in the pelagic facies changes

The structures of the grey nodular limestones ("Knollenkalk") of the Lower Ladinian are known well (ROSSI, 1965); the same applies for dark banded limestones ("Plattenkalk"), also called calcareo-siliceous rhythmites (ROSSI, 1964). These pelagic facies are quite different in their colour and diagenetic compaction. We shall emphasize here the importance of the bioturbation frequency and related diagenetic effects for the pelagic facies evolution of the "Knollenkalk" type and the "Vedessana" type facies. On the other hand, the dark to black Plattenkalk type facies shows fine banded or laminated undisturbed structures except for scarce transitions (bioturbated Plattenkalk, showing bioturbated calcareous grey sandwich between laminated facies). For comparison we ought to point out the well-known bioturbation structures in the pelagic Jurassic and Cretaceous sediments (see ELMI, 1981) and especially in the condensed facies and omission surfaces (BROMLEY, 1975). They have been much less described and interpreted in the Ladinian pelagic facies. Nevertheless, this discrimination between two different biofacies may be very important. The careful correlations of the lithological tuffitic and pelagic units support such an attempt to recognize the paleogeographical repartition of the bioturbation effect. The lithological condensation, classically attributed to the nodular limestones, seems to be of the same order of magnitude for the Plattenkalk and the Vedessana type facies.





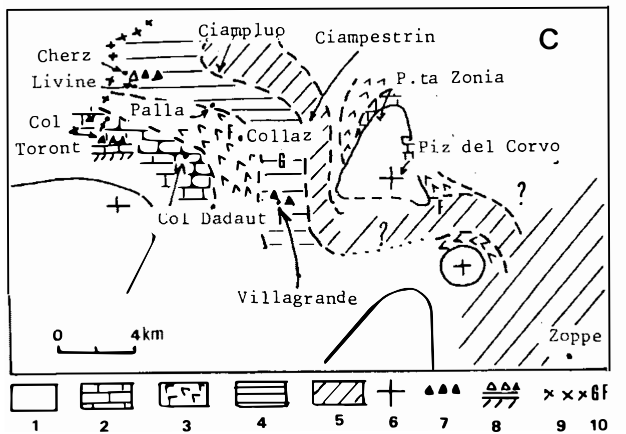


Fig. 8:

Paleogeographical map of the LPV (A) and UPV(B,C)distribution. A: the thin arrows show the supposed marine way of supply; the thick arrows point out the bioclastic resedimentation from adjacent occurring or supposed platforms.
Symbols: 1: main thickness lines of the LPV (main sequence); 2: way of pyroturbiditic transport; 3: calcarenite resedimentation; 4, 5, 6: supposed (6) or proved (4) paleorelief or sills and adjacent platforms (5).
B: UPV heteropy.
Symbols: 1: supposed way of tuffitic supply from a southern volcanic centre; 2: from a north-western centre; 3: megabreccia of the Fernazza Formation; 4: fine upper pietra verde; 5: coarser upper pietra verde; 6: nodular limestone of the upper Knollenkalk (UKK) in the north-eastern Dolomites and western Carnic Alps.
C: local repartition of the various upper pietra verde and heteropic upper Plattenkalk around the Marmolada / Cernera - Piz del Corvo and Monte Crot massives.
Symbols: 1 and 6: paleoreliefs; 2: calcareous pelagic sediments; 3: bevelled tuffitic UPV sequences; 4: Villagrande type sequences; 5: Ciampestrin type sequences; 7: intraformational breccias; 8: Aniso-Ladinian discordance (CROS, 1974) and associated polygenic breccias; 9: erosion zones of the Livinallongo Formation during the Upper Ladinian Fernazza deposit-stage; 10: C: coarse tuffitic facies; F: fine tuffitic facies.

c) Biofacies zonation in a recent marine basin

RHOADS & MORSE (1971) and BYERS (1977) have emphasized the biotic evolution of the sea-bottom communities in restricted or stagnant marine basins. This repartition of the benthic shelled epifaunas and the activity of resistent infaunas are arranged along a bathymetric profile and may be recognized in the fossil records. Their repartition in such basins is quite different compared with the open sea basins. The occurrence of a submarine sill is crucial for the water stagnation. So the dissolved oxygen originally present is removed by oxidation of organic matter (BYERS, 1977). The water column in an enclosed basin shows a tripartite layering (fig. 9) and the biofacies changes result from this oxygen-content-variation. The author applies this biofacies pattern of euxinic basins to some paleozoic North American series. The restricted water circulation induces the localization of an "erobic biofacies" in the shallow water turbulent realm, which is well mixed by surface-waves and currents. The aerobic biofacies is characterized by calcareous epifaunas and trongly bioturbated sediments in subtidal shelf depths. The deeper "dysaerobic biofacies" may be determinated by a dissolved oxygen content decreasing in quiet water.

There is no bottom calcareous epifauna but the sediment is bioturbated due to the activity of resistent infauna. The depth extension of the biofacies is defined by the lowering of the oxygen content under 0.2 ml/l. Under this biofacies boundary the "anaerobic" zone has no benthos at all, the sediment is undisturbed. The fine, dark mud and pelagic shells settle from suspension. The laminae are well preserved and often enriched in organic matter. BYERS (1977) calls the dysaerobic zone "pycnocline", but we shall not use this term because we are not able to determine any salinity or density stratification; we infer only an oxygen content evolution.

Bathymetric extension of the dysaerobic facies (pycnocline of BYERS, 1977) in some recent marine basins

We do not want to give too much emphasis to the bathymetric extension of the biofacies realms in various recent marine basins; we ought to refer to RHOADS & MORSE (1971) and BYERS (1977) for a biofacies interpretation. BYERS claims that the dysaerobic zone of the Black Sea extends from 50 m to 150 m depth, but that may be much less in small epicontinental shallow silled basins. RHOADS & MORSE emphasize that, if the sillls are deeper and the marginal basins more "open" oceanward, for instance like some basins of the California Gulf, the dysaerobic zone is more expanded, the lower boundary or water mixing depth is situated near the sill depth (500-700 m); such a depth of the anaerobiose boundary may characterize the ocean margin. This euxinic model of biofacies evolution seems to be well applicable to the Ladinian pelagic basin of the Dolomites.

2. Sedimentological interpretation of the biofacies changes

a) Bathymetric variations of the dysaerobic zone

The vertical stratigraphic evolution from one biofacies to another may be interpreted either by a variation of the depth of part of the basin alone, with a constant biofacies boundary, or by a twofold variation of the basin-depth and the zonal extension. The bathymetry of the lower boundary of the dysaerobic realm may change with the water circulation pattern in the basin and above the sills, which are outside the outcropping basin (fig. 9).

The Ladinian transgression is a general process in the Alps and we point out its importance in our paleogeographical reconstruction. The beginning transgression invaded the deformed and eroded Upper Anisian carbonate platforms; this caused shallow marine aerobic and dysaerobic water layers and a shallow anaerobiose boundary. During the transgression, the increasing depth of the basin and sills, especially of eustatic origin (BRANDNER, 1978), led to a deeper anaerobiose boundary in the Ladinian basin and so, we shall see, to a greater extension of the bioturbated nodular limestones.

b) Application of the biofacies pattern to the Dolomites Ladinian basin

Three successive stages of evolution may be recognized:

First stage:
The vertical rapid transition from the platform or from the Upper Anisian pelagic basin to the Livinallongo Formation is generally and locally associated with tectonic breccias (CROS, 1974; LAGNY, 1974). That is the first stage of the Ladinian transgression. The dark lower Plattenkalk, sometimes bituminous, is always deposited, except in the north-eastern Cadore where the bioturbated Vedessana facies occurs. The influence of the adjacent carbonate platform is marked by bioclastic resedimented facies in the southern and northern basin areas. The terrigenous supply still occurs in the north-east. This means a bathymetric gradient; the north-eastern basin bottom was shallower. Nevertheless, the anerobic boundary is not supposed to be deep, since the Plattenkalk biofacies outcropping in the north-western area, adjacent to the Cernera Mount (Monte Pore slope) lies on a dark Dasycladaceae-rich facies. This lower unit is bevelled on the Cernera - Piz del Corco Upper Anisian paleorelief. These anaerobic conditions were the rule in a semi-closed, irregular basin coming from the tectonic evolution of the Contrin (or Upper Serla) platform before the transgression.

The first tuffitic LPV deposits have been quickly and largely supplied into this deeper pelagic basin (less than 100 m deep) by proturbiditic volcanic events.

Second stage:
The nodular limestone biofacies units LKK and MKK are extended through the whole basin during the second main pyroturbidite of the LPV. The bioclastic resedimentation coming from the adjacent platforms remained effective only southward and north-westward, but the fine terrigenous supply stopped everywhere.

Locally, in the n° 4, 5, 6 sections, the LKK covers either directly another dysaerobic shallow facies (of Vedessana type) or an aerobic Plattenkalk intercalation, which brings out in relief the locally shorter and later formed passage under the anaerobiose boundary in this north-eastern part of the basin during the end of the first stage: this first stage of deepening occurred here later than elsewhere. As we have seen, the bioturbated LKK deposition is generalized under the main sequence of the LPV (80 m thick); so we have supposed a phase of deepening of the dysaerobic conditions.

This second pelagic stage of dysaerobic biofacies lasted for a long time during the LKK and the MKK sedimentation. The aerobic biogenous algal environment still occurred on the adjacent Ladinian platforms and locally settled once more on the top of the Cernera paleorelief. During that time the slightly

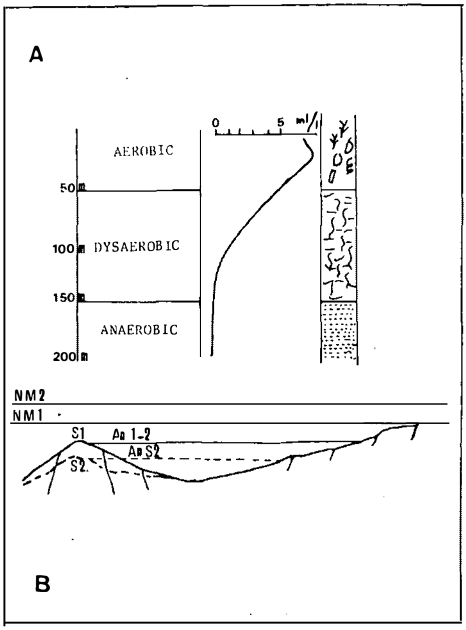
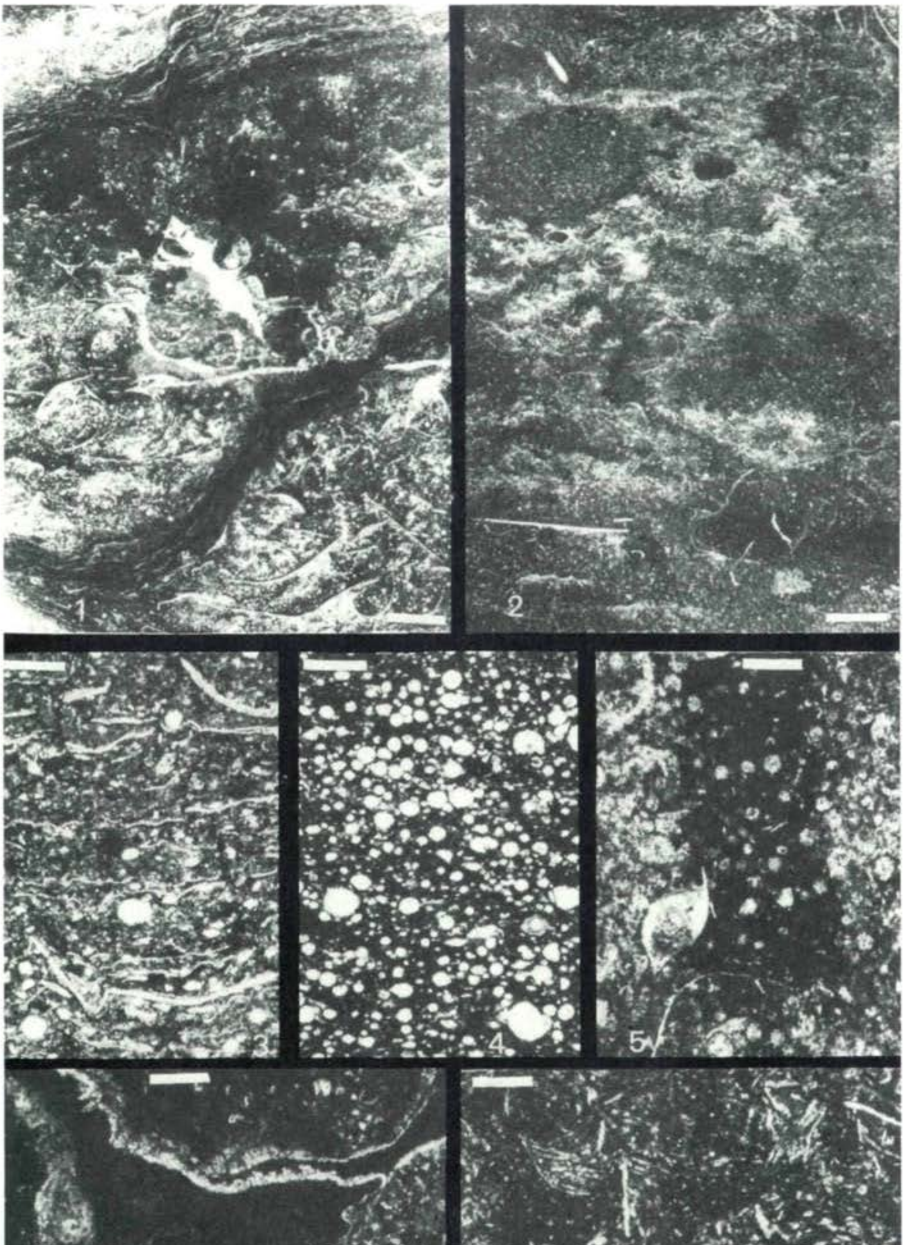


Fig. 9:

Biofacies repartition pattern in a basin closed by a submarine sill.
A: biofacies stratification (BYERS, 1977, modified) for the Black Sea.
B: sketch of the supposed evolution of the sea level driven either by a eustatic control (NM1, NM2) or by a sill depth increase (S1, S2).

Plate 1:

1: nodular limestone. The internodular diagenetic dark matrix does not cancel too much the original features. The vertical mixing of the micritic and shelly facies corresponds to a bioturbation effect. White line = 3 mm.
2: bioturbated hemipelagic limestone between nodular limestone beds in a "mixed-facies", characterizing the platform's outer edges, not modified by differential compaction. White line = 2 mm.
3: siliceous limestone "Plattenkalk" with *Daonella* and radiolarians non bioturbated. The compaction effect just enhances the original laminations. White line = 800 micrometres.
4: siliceous dark Plattenkalk with radiolarians non bioturbated. White line = 800 micrometres.
5: bioturbation feature (top: left), well individualized by the early cementation; an internal sediment fills the remnant void. Sample coming from a hemipelagic calcarenite ("Vedessana facies") supposed to be shallower than the lower nodular limestone. White line= 800 micrometres.
6: opened bioturbation feature (top left) well-marked by the early cementation and the internal sediment fills the lower void coming from a hemipelagic calcarenite (Vedessana facies), supposed to be of shallower origin than the lower nodular limestone. White line = 800 micrometres.
7: bioturbated *Daonella* biomicrite, MKK. White line = 800 micrometres.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deeper adjacent paleorelief (Piz del Corvo) was covered by the onlapping dysaerobic biofacies or passed laterally to the aerobic fossiliferous and algal limestones. This pattern supports the assertion that the nodular limestones were formed on quiet, very moderately deep bottoms, heteropic with an aerobic biofacies along moderate slopes. On the other hand we have seen that the permanence of basinal bioturbated biofacies during the long time of huge southern tuffitic supply (LPV) emphasizes the larger bathymetric extension of this second stage dysaerobic realm. This bathymetric increase is known in the whole Dolomites and Carnic Alps till the Dierico area (west of Pontebba) during the Lower Ladinian. We think that this deepening was moderate; we suggest, as a working hypothesis, a bathymetric value less than 300 m, which is not far from an average value of the depth of the dysaerobic zone in the Black Sea model, placed in a much too much continental position, and the Gulf of California model, placed in a much too much perioceanic position. Of course, the depth supposed above would be that of the shallowest sills in the whole Ladinian basin.

Third stage:
It corresponds wo the Upper Plattenkalk unit which indicates that the anaerobic, deeper conditions extended throughout the basin, even above the former bordering biogenous platforms or the local aerobic paleorelief.

The bioclastic resedimentation disappeared, except in the northwestern area. This is a new phase of the Ladinian transgression and deepening. But the dysaerobic "Knollenkalk" maintained during the turbiditic deposition of the UPV in the adjacent western Carnic Alps (cf. n° 4 section, Rigoladis and Rio Sappada sections cf. fig. 8). This predominant deepening during the third stage is associated with some tectonic instability of the platform outer part and basin transitions; this deepening follows a two-step-evolution in the central area, first with the occurrence of breccious strata in the UPK and then with the Fernazza breccia and olistostrome (CROS, 1974; VIEL, 1979) at the end of the uppermost Ladinian. Inside the basin these tectonic events are marked by intraformational fracturation or slumping deformation and brecciation, which proves the secondary effect of this tectonic phase (CROS, 1967).

GENERAL CONCLUSION

The stratigraphic study of the Livinallongo Formation points out the main lithologic tuffites and pelagic units already defined in the Italian Dolomites. The detailed description of the numerous facies and thickness-changes of the pietra verde and adjacent pelagic sediment points out the two stages of pyroclastic activity coming from a main southern centre which is supposed to have been outside the Dolomites. Some subsidiary centres supported distinct pyroclastic and epiclastic supplies coming first from the south-east and then from the north-west.

The paleogeographical distribution of the main tuffitic units depends on the basin bottom morphology and the adjacent platform development. The lower pyroturbidites accumulated intensively in the south-eastern part of the basin, up to the internal shallow bottom area of the Cernera - Piz del Corvo, they are then scattered as an isopachous sheet (the "main sequence") in the deeper central-western Livinallongo areas; they disappear in the shallower northern and western areas where they are replaced by thin cineritic tephra beds. There is also a modification north-eastward by the mixing of two types of pyroturbidites of distinct origin. The bottom morphology had been modified during the upper volcanic stage, as shown by the turbiditic layers repartition. The tectonically shaped Dolomites basin caused a distinct turbiditic dispersion pattern, compared with the adjacent western Carnic basin. Its eastern part is marked by a decrease of the tuffitic supply coming from the south. This regions seems to be distinct from the eastern synchronous supply because of a gentle slope or sill connecting it with the Carnic Alps.

The pyroturbidites are caused by a few big eruptive events; the turbidites show a more continuous evolution. The comparison of several pyroturbidites along the whole Lower Ladinian basin might lead to a better definition of the intricated volcanogenic and paleogeographical evolutions.

The pelagic units correlation favours the relative bathymetric interpretation based on the bioclastic or breccious resedimentation and on the bioturbation.

The three aerobic, dysaerobic and anaerobic biofacies have a paleogeographical repartition which is deduced from the sedimentological model suggested by the comparison with recent silled marine euxinic basins.

The interpretation of the biofacies relationship supports the distinction of a three stages evolution of the Lower Ladinian transgression. The succession of bioturbated and unbioturbated biofacies may result from a progressive increase of the sill depth and of the proper depth of the enclosed pelagic basin.

The bathymetric environment suggested by the comparison with recent marine basins may increase from more than 50 m to 300 m for the grey nodular limestones, taking into account the heteropical relations in the Dolomites basin. This points out the paleogeographical importance of the submarine sills and associated emerged ridges, dividing the Ladinian basin and separating it from the open Triassic sea or ocean. The tectonic evolution of such paleogeographical lineaments may be deciphered by the terrigenous supply analysis, the nature and repartition of the littoral and continental facies surrounding the sills or ridges. The recognition of the pyroclastic centres' localization and their activity along or near these ridges ought to be an important progress in documenting us about the deep structural and magmatic evolution of this unstable marginal Ladinian basin.

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