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Prealpine events along the eastern Insubric Line (Tonale Line, northern Italy)

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ABSTRACT

The eastern extension of the Insubric Line (the Tonale Line in the Valtellina) separates a northern Tonale Zone from a southern belt of Edolo Schists. Both zones are important in order to evaluate the early history of this most important alpine structure, documented by various tectonic, metamorphic and intrusive prealpine events. In the large body of argillaceous-sandy sediments of Edolo, limited to the north by the Tonale Line, palynological investigations suggest Ordovician and Silurian ages.

ZUSAMMENFASSUNG

Die östliche Fortsetzung der Insubrischen Linie (Tonale-Linie im Veltlin) trennt eine nördliche Tonale-Zone von den südlichen Edolo-Schiefern. Beide Zonen sind für eine frühe Anlage der wichtigsten alpinen Störungszone von Bedeutung, die durch verschiedene voralpine tektonische, metamorphe und Intrusionsphasen angedeutet ist. In dem von der Tonale-Linie im Norden begrenzten mächtigen Ablagerungsraum der tonig-sandigen Edolo-Sedimente konnte palynologisch Ordovizium und Silur nachgewiesen werden.

1. The regional geology

The Edolo Schists are important old Paleozoic metasediments of the Southern Alps, located in the Valtellina and the upper Val Camonica where the little town of Edolo, the type locality, is situated. In the south they are transgressed by and subsequently thrust on the Permo-Triassic (locally Carboniferous) sediments of the Orobic Alps. In the north they border with a conspicuous tectonic contact the Tonale Line, the eastern extension of the Insubric line, known as the major alpine dislocation which delimits the Central from the Southern Alps (CORNELIUS & FURLANI 1930, GANSSER 1968, LIBORIO & MOTTANA 1969, LARDELLI 1981, LAUBSCHER 1971, 1983, WIEDENBECK 1986, SCHMID et al. 1987).

The Edolo Schists are overprinted by various structural and metamorphic pre-Alpine events. The metamorphism increases from east to west, where the Edolo Schists grade (locally with faulted contacts) into the characteristic Morbegno gneisses, followed west of Lake Como by the Ceneri–Strona zone with a high amphibolite to granulite facies. Evidently the latter connection is doubtful, complicated by pre-Alpine fault zones such as the Val Colla Line and the Musso Line, both pre-Triassic but post-Carboniferous

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(infolded unmetamorphic Carboniferous). The E–W trending Musso Line (a possible eastern extension of the Val Colla Line) brings sillimanite gneisses of the Olgiasca zone in the uppermost Lake Como (its metamorphism and structures cut by discordant pegmatites with ages of 200–250 my, HANSON et al. 1966) against low grade, partly retromorph phyllites and phyllonites, together with a marked change in structural alignment (EL TAHLAWI 1965). In the lower Valtellina, where the Musso line is believed to merge with the Tonale Line, outcrop 'gneiss chiari', supposed to be meta-arkoses topping the pre-Carboniferous 'basement' (EL TAHLAWI 1965).

Within this geological frame we are interested in two major geological units, the Tonale Zone in the north and the Edolo Schists in the south, divided by the Tonale line (Fig. 1, Plate). Dating of the Edolo Schists was of particular interest since it would give further facts in order to understand the pre-Alpine events in this area.

2. The Tonale Zone

The Tonale Zone consists of various high grade micaschists and gneisses, locally with garnets and sillimanites, of amphibolites, lime silicates and marbles, the latter frequently developed as characteristic 'fluidal limestone mylonites' and related to the Tonale Zone blastomylonites. Rare ultrabasic lenses occur north of Teglio (LARDELLI 1981), and southeast of Tirano elongate bodies of pyroxene gabbros are intercalated in the Tonal Zone (Motto della Scala gabbros). Their originally discordant intrusive contacts have been subsequently tectonized and expose sheared amphibolites. They could be compared to the pre-Alpine gabbros of Sondalo in the Upper Valtellina. All rocks of the Tonal Zone

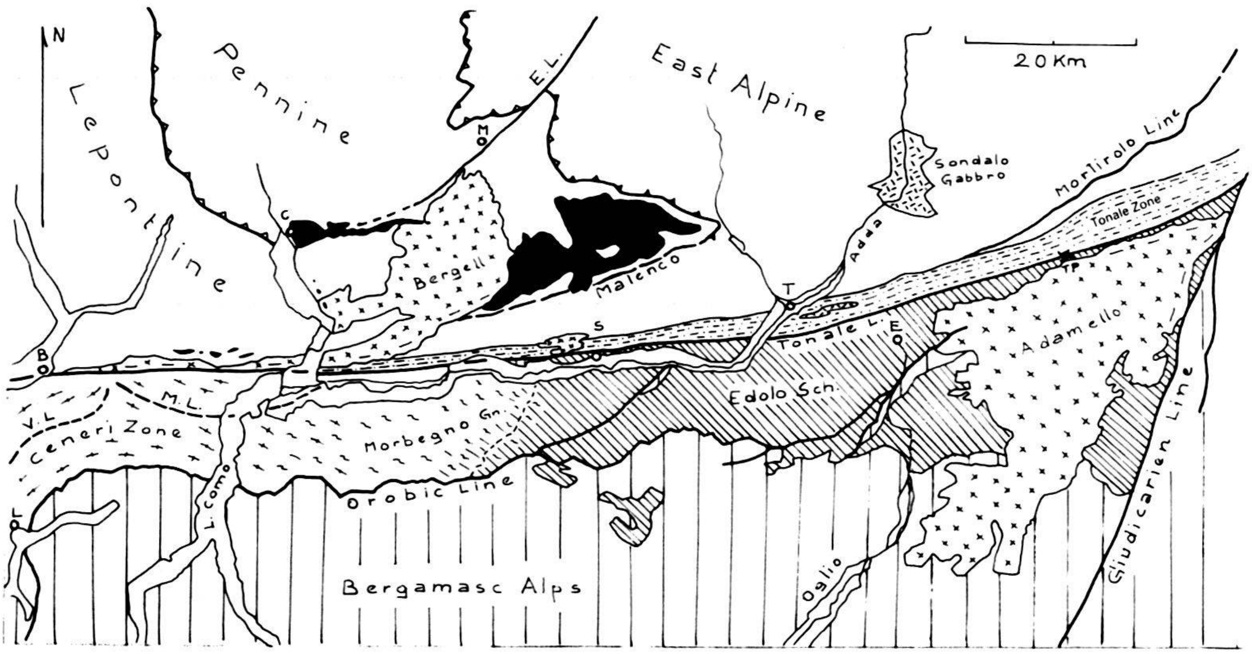


Fig. 1. The Tonale Line and surrounding areas

B: Bellinzona	E: Edolo	M: Maloya	TP: Tonale Pass
C: Chiavenna	L: Lugano	S: Sondrio	V.L.: Val Colla Line
		T: Tirano	M.L.: Musso Line

have undergone various phases of post-metamorphic deformations which increase towards the Tonale Line, resulting in mylonites and ultramylonites. Into these high grade metamorphosed and tectonized rocks (blastomylonites) intruded discordant pegmatites. Preliminary muscovite ages from two localities vary from 230 my (north of Dubino) to 160 my (north of Berbenno) (LARDELLI 1981, p. 95). Together with the Tonale Zone rocks the pegmatites have subsequently been overprinted by a pronounced cataclastic event (late, Alpine?). However the fact remains that a conspicuous mylonitisation of the Tonale Zone antedates the intrusions of the pegmatites, which could be related to the Olgiasca types. In spite of the local complications the 2 km wide Tonale Zone is surprisingly constant in its composition, from south of Bellinzona to east of the Tonale Pass for 140 km. This fact was already evident to SALOMON, who 1905 coined the name Tonale Zone. Farther to the west, similar sections are known along the Insubric line west of Locarno, though reduced by tectonic complications such as the presence of the Ivrea Body and the conspicuous backthrusting (SCHMID et al. 1987). The latter is not marked east of Locarno, where the later Insubric phases are dominated by vertical uplifts. Here backthrusting has been taken over along the Orobic Line! The striking Oligo/Miocene uplift of the Bergell (WAGNER et al. 1977) seems not to be related to the Insubric phase.

According to FUMASOLI (1974) the late lamination of the Tonale Zone (blastomylonites) happened under amphibolite facies prior to the emplacement of the Bergell tonalites. HEITZMANN (1975) thinks that the pre-metamorphic blastomylonites recrystallized under an Alpine phase. The regional importance and implications of the known facts are formulated by LARDELLI (1981, p. 200): «Zwischen Masino and Teglio muss eine alpine Rekristallisation ausgeschlossen werden (Muskowit-Alter der Pegmatite 160–230 my), und die prämetamorphe Mylonitisierung wäre mindestens herzynisch. Da diese Zone von der Val Morobbia bis über den Tonale-Pass hinaus immer die Tonalelinie im Norden begleitet, wäre dies ein ausserordentlich wichtiges Indiz für sehr alte, bedeutende Bewegungen in dieser Zone – so bedeutend, dass mir die Interpretation dieser Gesteine als Blastomylonite noch zu wenig gesichert erscheint!»

3. The Edolo Schists

While the Tonale Zone may have undergone pre Alpine as well as Alpine events, the Edolo Schists have only locally been affected by an Alpine overprint. They show a pre-Alpine greenschist metamorphic facies at the type locality, the little town of Edolo (clorite, biotite ± garnet). This metamorphism increases from east to west and north to south. Not considered is here the local and much younger contact metamorphism caused by the Adamello and Bergell (Sondrio) plutons. Metamorphic changes are often limited and stressed by tectonic belts. Characteristic is the southern border with the transgressive Orobic sediments (Carboniferous–Triassic) which has locally developped into rather complicated northheading and southwards directed thrusts (backthrusts) and faults (Orobic Line). Along this belt occur tectonized gneiss bodies within the southern Edolo Schists. They resemble the Morbegno albite gneisses, and may represent a higher grade metamorphic facies of the Edolo Schists. Here they seem to form the core of mega isoclinal folds. An actual "pre-Edolo basement" is not known in the Valtellina area.

Towards the contact with the Tonale Line the Edolo Schists are tectonized and along the contact there occur locally boudinaged relics of dolomite of probably Triassic age.

North of Teglio, the locally discordant schists are dragged parallel towards the Tonale Line suggesting a right-lateral shear. Boudinage and shearing effects are most likely Alpine events related to the Tonale Line. Similar contacts, with dolomitic lenses can be observed east of Monte Padrio as well as east of Ponte di Legno and further on the Tonale Pass. Here dolomites, banded marbles, and even rauhwackes and quartzites follow the contact but also do crop out on the southern belt of the Tonale Zone. In spite of being strongly disrupted, the dolomitic rocks may represent a Triassic sequence, but rather of a Penninic aspect than of the well-known East Alpine type. This suggestion, which evidently needs further investigation, would have important structural implications.

The actual Edolo Schists consist predominantly of sericitic phyllites. With an increasing quartz content they grade into well banded quartzitic phyllites alternating with layers of very fine grained and well bedded quartzites, the "Quarzlagenphyllite" of SALOMON (1896). One also notes a slight carbonate content, but real carbonatic horizons are rare, except for some calcschists, marbles and dolomitic schists to the west of Teglio. Contacts are always gradual. Greenschists with chlorite-epidote, chlorite-biotite and chlorite-hornblende crop out locally. They show the same deformations as the phyllitic rocks, are concordant and may represent metatuffs. Also local are concordant intercalations of black graphitic phyllites. They seem to form stratigraphic horizons and should be distinguished from phyllonites which do occur frequently within the Edolo Schists.

The original sediments forming the Edolo Schists were probably over 4000 m thick, though repetition by faulting and isoclinal folding of the rather monotonous section render an estimate difficult. The relations of crystallisation and deformation suggest three folding phases and two different cataclastic events affecting the Edolo schists after their sedimentation. They increase in intensity towards the Tonale Line (Fig. 2). Here older mylonites are seen refolded within the micaschists (LARDELLI 1981). All these variously deformed and metamorphosed sediments are discordantly cut by numerous hornblende porphyrite dykes. Except for some late fracturing, the latter have been little affected by postintrusive events. With their hornblende ages of 96–80 my (MC DOWELL 1970) they clearly show that the latest structural and metamorphic overprint of the Edolo Schists is pre Middle Cretaceous. The two analyzed samples were collected at Tresenda (southeast of Teglio) and at Castelvetro (WSW of Teglio). The hornblendes from both dykes are

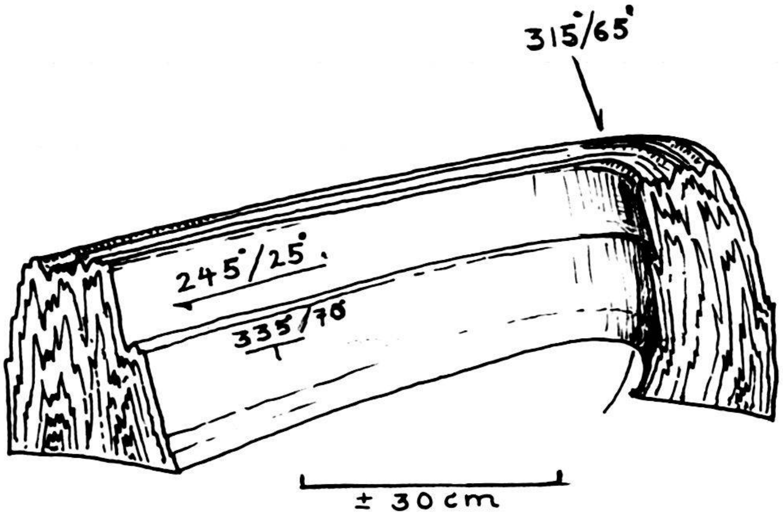


Fig. 2. Refolding of intensely tectonized Edolo Schists. Summit of Monte Padrio, just south of the Tonale Line.

surprisingly fresh and idiomorph, a fact which can be observed at many other similar dykes. The dykes also cut through phyllonitic belts and in one of the dykes Lardelli observed a xenolith of a folded mylonite (LARDELLI 1981, Fig. 39).

SCHIAVINATO (1950) distinguished in the wider Edolo region two types of dyke swarms: pre-tonalitic hornblende porphyrites and post-tonalitic dykes of various composition related to the late phases of the Adamello intrusions. Other Italian authors (CRESPI 1961, LIBORIO & MOTTANA 1969) suggested late Tertiary ages, since the porphyrites are supposed to be cutting 'alpine' mylonites along the Tonale Line. Field observation and age dating have clearly disproved these late Alpine events.

Paleontological dating of the widespread, fine sandy and argillacious sediments, the protoliths of the Edolo Schists was most difficult but eventually lead to some most interesting results. Constraints were given by the transgressive Upper to Middle Carboniferous, while the Carta Geologica d'Italia, sheets Tirano and Sondrio place the Schisti di Edolo into questionable Precambrian. Regionally the Edolo Schists are incorporated in the Southalpine basement.

4. Palynological investigations

Until recently moderately to highly metamorphic rocks have been considered as being largely unfossiliferous. The palynological examinations carried out in Europe during the last fifteen years (PANTIĆ 1973, 1978, PANTIĆ & GANSSER 1977, PANTIĆ & ISLER 1978, PANTIĆ, HOCHULI & GANSSER 1981, KLINEC, PLANDEROVA & MITEA 1975, and others in Czechoslovakia, and quite recently also by PFLUG & REITZ 1987) however, have proved that the methods based on organic microfossils like palynomorphs contribute to the age determination of these metamorphic rocks.

The Edolo Schists were considered unfossiliferous, being overprinted by various metamorphic and structural Pre-Alpine phases. But despite the fact the organic remains are usually graphitized and pyritized, it still was possible to separate a certain number of palynomorphs (spores, acritarchs and chitinozoans) and, with much difficulty, to determine the age of some sequences of the Edolo Schists.

The palynological examinations were carried out based on 85 samples collected with more than 200 slides prepared from them. The best results obtained during the study are from samples of Section I, a locality on the road Passo Aprica–Galleno near Scala, at the mouth of the creek (coordinates: 813.850/116.400); Map Brusio 1:50,000 (no. 279). Here seven samples (IA–IG) were taken from black shales and micaceous schists.

In slide I/F the following palynomorphs could be determined:

Spores	*Ambitisporites* cf. *avitus* HOFFMEISTER
	Ambitisporites dilutus (HOFFMEISTER) RICHARDSON & LISTER
	cf. *Synorisporites verrucatus* RICHARDSON
	Archeozonotrilites sp.
Acritarchs	*Trachysphaeridium* sp.
	Multiplicisphaeridium sp. (cf. *cladum* DOWNI & LISTER)

This slide also contains a few fragments of chitinozoans.

In Section II/F from another locality, 3.5 km NNE of Edolo, coordinates 824.300/120.870) the following acritarchs could be identified:

Trachysphaeridium sp.
?*Enneadikosochenia* sp. (cf. *granulata* COLBATH)
Lophosphaeridium sp.

and, in addition, a few fragments of chitinozoans (probably remains of the genera *Lagenochitina* and *Desmochitina*).

Most of the other samples only contain small organic remains, usually as graphitized or pyritized fragments of acritarchs and chitinozaoans.

Only about 20% of the other samples collected (particularly those from the region Teglio: L 48, L 84, L 107, L 123) contain recognizable remains of the genera *Protoleiosphaeridium* and *Zonosphaeridium*. Fragments of chitinozoans seem to be present in almost all samples.

Some samples also contain remains of opaque plant tissue.

The preservation of organic substance is altogether poor due to the strong effects of metamorphism. It is of interest to note that the organic substance is somewhat 'mosaically' changed. This applies in particular to certain entire forms or fragments of acritarchs.

The following identified palynormorphs may be used in the age determination of certain sequences of the Edolo schists:

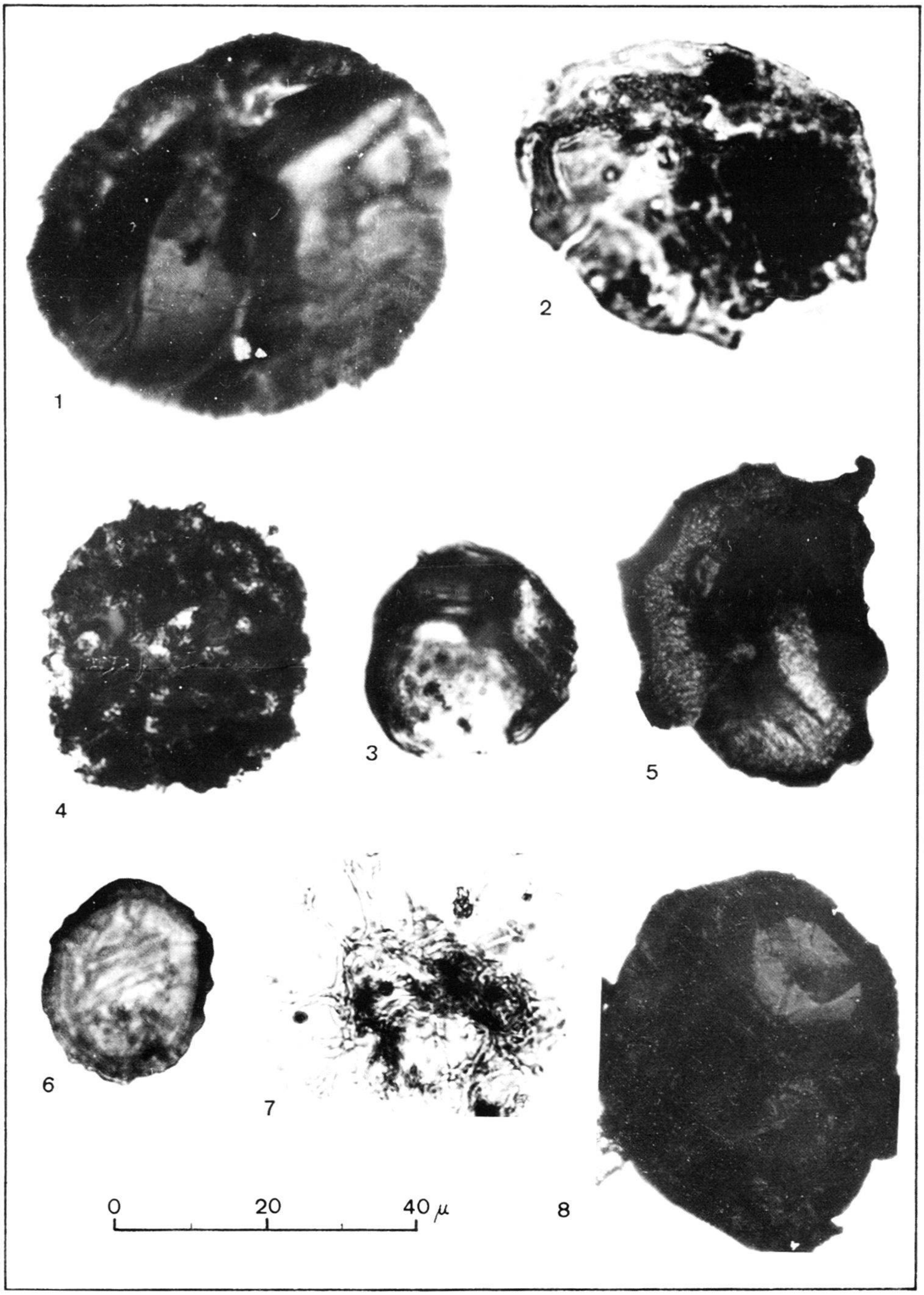
Spores

a) *Ambitisphorites* cf. *avitus* HOFFMEISTER. Several badly preserved spores (usually fragments only) are very close to that species. RICHARDSON & IOANNIDES (1973) state that it varies in size from 47 to 87 μm. The size of our best specimen (Fig. 3/1) measures 57 μm. This species was described for the first time from the Lower Silurian of Libya. Later, it was also identified in Silurian sediments of Wales and France (RICHARDSON & IOANNIDES 1973; HILLET et al. 1985, D'ERCEVILLE 1979).

b) *Ambitisporites dilutus* (HOFFMEISTER) RICHARDSON & LISTER. This species was also described for the first time from the Silurian of Libya. RICHARDSON & IOANNIDES (1973) state that its size varies from 21 to 48 μm. The specimen on Figure 3/2 measures 40 μm. According to our knowledge of today, this species may be considered an indicator of a Silurian age (PFLUG & REITZE 1987).

c) *Synorisporites verrucatus* RICHARDSON & LISTER. Our form (Fig. 3/3) shows close similarity to the species *Synorisporites verrucatus* RICHARDSON & LISTER, which is said to vary from 17 to 33 μm. The size of our best preserved specimen measures 27 μm. Unlike somewhat more complex forms of this species, this type of spores usually occurs in the Early Silurian (RICHARDSON & IOANNIDES 1973).

Fig. 3. Photographs of selected palynomorphs
1 *Ambitisporites* cf. *ovitus* HOFFMEISTER, Slide I/F, 038
2 *Ambitisporites dilutus* (HOFFMEISTER) RICHARDSON & LISTER, Slide I/F, 038
3 cf. *Synorisporites verrucatus* RICHARDSON, Slide I/F, 038
4 *Trachysphaeridium* sp., Slide II/F, 091.38
5 *Enneadikosochenia* sp. (cf. *granulata* COLBATH), Slide II/F, 090.31
6 *Lophosphaeridium* sp., Slide II/F, 080.29
7 ?*Multiplicisphaeridium cladum* (DOWNIE) LISTER, Slide I/F, 097.2.2
8 *Leiosphaeridium* sp., Slide II/D, 046.1
The slides are deposited at the Museum of the Institute of Regional Geology and Paleotology, University of Beograd.


1
2
4
3
5
6
7
8
0
20
40 μ

Microplankton

Acritarchs

In addition to the above listed spores, a number of usually poorly preserved acritarchs was observed in the examined Edolo samples. A relatively well preserved form of the genus *Multiplicisphaeridium* (? *M. cladum* DOWNIE & LISTER) is worth mentioning. This form (fig.3/7) is better preserved compared with the other palynomorphs, thus raising some doubt as to its actual belonging to the sediments in which it was found. The species it resembles most is known from the Ordovician. Another badly preserved acritarch, shown on Fig. 3/5, may be assigned to *Enneadikosochenia granulata*. This species is known from the Ordovician (COLBATH 1979).

Relatively frequent forms are also poorly preserved opaque sphaeromorphous acritarchs. For the major part they are oval forms with vague ornamentation. They usually belong to the genera *Leiosphaeridium* (Fig. 3/8) and *Trachysphaeridium*. It is off interest that these forms are more frequent in samples collected from the second profile (samples II/A–II/F). Only acritarchs and fragments of chitinozoans but no Silurian spores have been found in this section.

Chitinozoans

Most samples revealed quite poorly preserved usually opaque fragments of chitinozuoans. Based on them the possible presence of the following genera can be assumed: *Ancyrochitina* sp., *Lagenochitina* sp., *Conochitina* sp., and *Desmochitina* sp. It appears that some forms from section II may represent Ordovician chitinozoans.

Results

1. 80 samples from 15 different localities I–XV (Plate) and four samples of Tomaso Lardelli (L) were collected in the Edolo Schists to investigate the possible presence of palynomorphs. The analysis of some 200 slides prepared from these samples showed that most of the collected localities proved to be either barren or that the state of preservation of the organic remains was too poor for a generic or specific assignment. Only localities I and II contained material that allowed for the identification of palynomorphs (spores of early land plants) and microplankton (acritarchs and chitinozoans). Their preservation in these samples was found to be very variable (graphitized, pyritized or 'mosaically' altered) which is explained by the different degree of metamorphism within the Edolo Series.

2. The prevalence of Silurian spores (*Ambitisporites* cf. *ovatus*, A. cf. *dilutus* and *Synorisporites* cf. *verrucatus*) and of the accompanying microplankton proves that the sequences in profile I Passo Aprica–Galleno near Scala pertain to the Silurian (?Late). No spores of a more complex structure as *Emphanisporites*, *Acinosporites*, *Ancyrospora*, occurring since the Lower Devonian, were observed.

3. It may be assumed that there are also Ordovician sequences within the thick series of the Edolo Schists. The presence of specific forms of acritarchs and the general appearance of certain "associations of chitinozoans" point to such an assumption.

4. The presence of marine microplankton indicates a marine nature of the Ordovician–Silurian deposits of the Edolo Schists.

Finally the results of this study allow for a close comparison between the palynomorph associations in the Edolo Schists, and those from Silurian deposits of Libya (HOFFMEISTER 1959, RICHARDSON & IONANNIDES 1973, and HILL et al. 1985).

This preliminary work shows that, if palynological methods are applied, the metamorphosed series of the Edolo Schists, considered unfossiliferous until recently, can now be dated stratigraphically in that at least a part of it is of Silurian and Ordovician age.

5. Conclusions

The fact that part of the over 4000 m thick Edolo Schists, originally argillaceous to fine sandy marine sediments, contain microfossils of Silurian–Ordovician age and follow the Insubric Line stress the importance of pre-Alpine events in this area, which are also documented in the history of the Tonale Zone. The thick sediments of Edolo may suggest deposits of a passive continental margin or represent a large basin (lack of coarse detrital material). Little is known of its subsequent development, though our preliminary investigations suggest relations to an old Insubric alignment, which may have formed a northern tectonic frame.

Structurally, the Edolo Schists seem to dip steeply to the north. This regional picture is however complicated by intense local tectonics which, based on the available information and the rather uniform lithology, are difficult to interprete. The samples suggesting a Silurian and Ordovician age form a nearly E–W oriented belt, passing from north of Edolo over the Aprica Pass into the region of Teglio. This belt seems to coincide with the stratigraphically younger section of the Edolo sediments, assuming the northwards dip is normal. This belt also parallels the Tonale Line and steepens toward the contact, where steeply infolded (down faulted) remnants of probably Triassic carbonates crop out. Southwards we note older sections of the Edolo Schists where the metamorphism has locally increased, documented by the crystalline cores (Morbegno facies) of isoclinical folds. Here we also note the marked backthrusting of the Edolo "crystalline" over its normal cover (Carboniferous–Triassic) along the Orobic Line. This backthrusting contrasts with the downfaulting of the Edolo belt along the Tonale Line.

Various events have involved the Edolo Schists until the present picture was reached and similar events have also been noted along the Tonale Zone. Here discordant pegmatites intruded originally already tectonized belts (phyllonites) and seem to belong to the widespread Olgiasca event (average 210 my). To trace pre-Alpine phases in the Alpine overprinted Tonale Zone needs much detailed work which can prove difficult in the western parts of the Valtellina where the Alpine effects are more pronounced. Latest ages from the Mello region (WIEDENBECK 1986) do reflect this. Micas from the Tonale Zone average 25 my while some mylonites seem to vary from 105 to 220 my (probably low temperature and relictic older micas). Hornblendes from the Morbegno gneisses show ages around 360 my, which may reflect the time the Edolo sediments have been metamorphosed.

The widespread hornblende porphyrite dykes south of the Tonale Line, averaging 90 my, cut all previous structures and postdate all metamorphic events. These Eoalpine intrusions stress the fact that the intense folding and mylonitisation in this area are pre-Alpine. Only the rather weak cataclastic overprint of some dykes is related to later phases which also affected the present Tonale Line (beginning of dextral movement?).

Future structural investigations and selected critical age dating are needed to further verify the present deductions which, based on preliminary results only, draw attention to the often neglected pre-Alpine events.

Acknowledgments

Peter Hochuli was substantial in collecting the field samples and assisted in the preliminary palynological investigations. Due to the initiative of Hans M. Bolli the present paper could be published. The palynological work was supported by a research grant of the Federal Institute of Technology, Zürich.

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Topographic map

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b) Palynology

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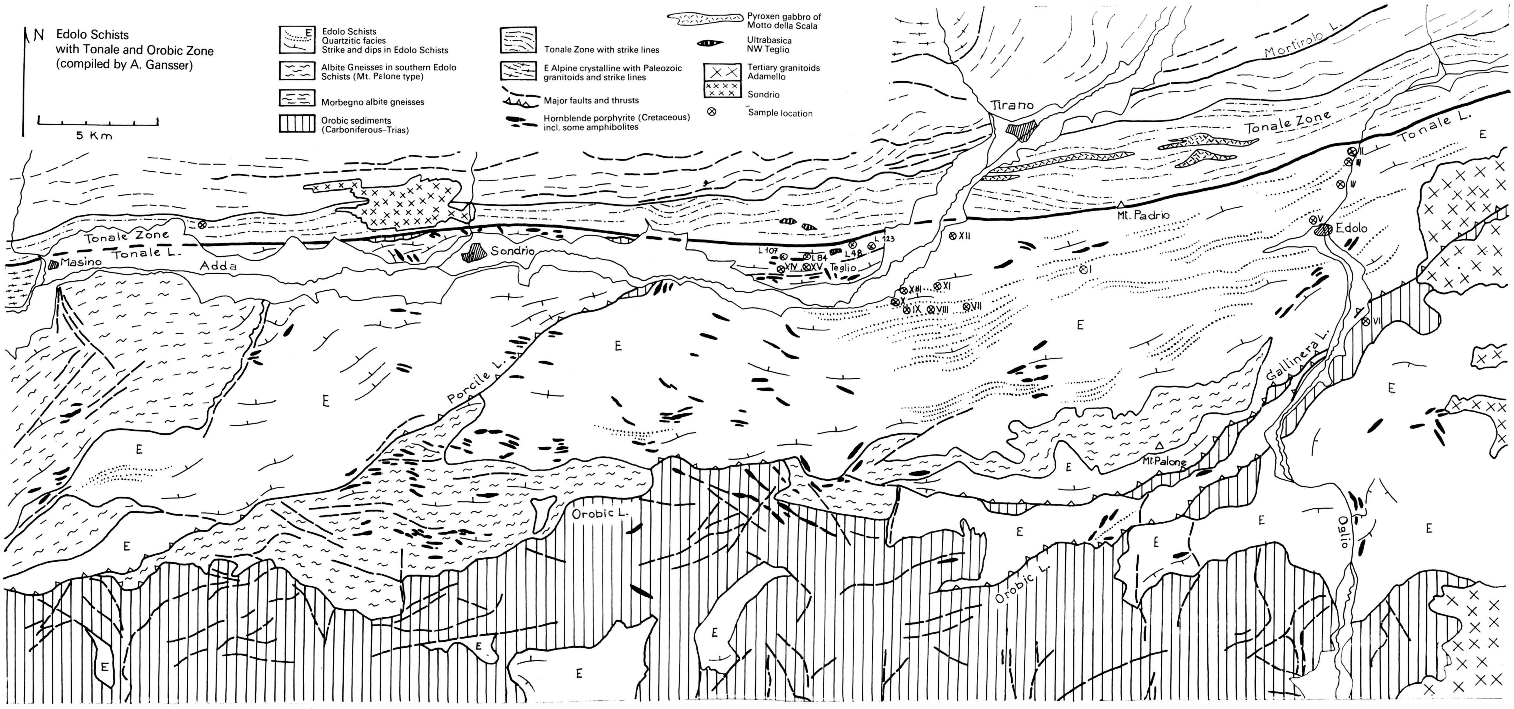
P.S.

Interesting facts on Prealpine events of a central part of the Orobic "basement" are presented by MILANO et al. in Eclogae geol. Helv. *81*/2, 273–293. They were recieved after our paper was completed.


N
Edolo Schists
with Tonale and Orobic Zone
(compiled by A. Gansser)
5 Km
E
Edolo Schists
Quartzitic facies
Strike and dips in Edolo Schists
Albite Gneisses in southern Edolo Schists (Mt. Palone type)
Morbegno albite gneisses
Orobic sediments (Carboniferous–Trias)
Tonale Zone with strike lines
E Alpine crystalline with Paleozoic granitoids and strike lines
Major faults and thrusts
Hornblende porphyrite (Cretaceous) incl. some amphibolites
Pyroxen gabbro of Motto della Scala
Ultrabasica NW Teglio
Tertiary granitoids
Adamello
Sondrio
Sample location
Tirano
Mortirolo L.
Tonale Zone
Tonale L.
Mt. Padrio
Edolo
Masino
Adda
Sondrio
Teglio
Porcile L.
Orobic L.
Gallinera L.
Mt Palone
Oglio