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# The profile "CROP Alpi Centrali"
# *Il profilo CROP Alpi Centrali*

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ABSTRACT - The "CROP Alpi Centrali" Project is a multidisciplinary research programme, with the application of seismic, gravity, electric and magnetotelluric methods, exploring the Central Alps, from Spluga pass to Bergamo and the Po plain.

The transect was based primarily on seismic data acquisition and was founded by CNR – CROP Strategic Project. It was subdivided into three segments (CROP C-ALPS/a, C-ALPS/b and C-ALPS/c and /d). The main scientific objective of the "CROP Alpi Centrali" transect was to reveal the crust image across the Alpine collisional chain: from the "Milano belt" (southern margin) to the Penninic units, in the core of the Alps, continuing toward the South the Swiss NRP20-E1 profile.

The seismic section shows three crustal domains stacked over the European Moho: the European crust towards the North, the Penninic-Austroalpine units at the centre, blocks of the Adriatic crust towards the South. These images fit the known surface geological data and the proposed geodynamic evolution of the Alpine chain:

1) The subduction of the oceanic crust beneath the African plate generated an accretionary prism with several fragments (the future nappes) affected by a differentiated eo-Alpine metamorphism and by a general northwestward transportation. The stack of Penninic and Austroalpine nappes is a consequence of the subduction.
2) A pre-Adamello deformation phase within the Southalpine complex reveals the presence of sud-vergent movements opposite to the eo-Alpine vergence.
3) The wedging of the Adriatic crust under the already formed Penninic nappes compels the whole Penninic-Austroalpine system to move vertically and to backthrust over the Southalpine complex, during the late phase of the Alpine orogenesis: the Insubric milonites are generated and the sud-vergent thrusts of the Southern Alps are built.

KEY-WORDS: Central Alps, reflection seismic, deep crust.

RIASSUNTO - Nell'ambito del Progetto Strategico CROP (CROsta Profonda) del CNR, il profilo "CROP Alpi Centrali" esplora la struttura profonda delle Alpi Centrali, dal Passo dello Spluga a Bergamo, applicando metodologie sismiche, gravimetriche, elettriche e magnetotelluriche e integrando successivamente i dati geofisici con i dati della geologia di superficie. I tre segmenti in cui è suddiviso il profilo (CROP C-ALPS/a, C-ALPS/b and C-ALPS/c and /d) attraversano le principali unità e lineamenti delle Alpi: le falde Pennidiche e Austroalpine, la Linea Insubrica, il Complesso Sudalpino (o Alpi Meridionali) con una porzione di Basamento+Copertura che giace sommersa sotto i depositi Plio-Quaternari della Pianura Padana (fig. 1).

Combinando e integrando i risultati del Progetto CROP-Alpi Centrali con quelli del progetto svizzero NRP20-E1, che è quasi sul prolungamento del primo, sono state individuate alcune immagini sismiche, interpretate poi in chiave geologica con un grado di affidabilità che varia da caso a caso. In particolare, nel profilo CROP Alpi Centrali:

- a nord del Lineamento Insubrico, alcuni riflettori suborizzontali poco profondi (tra 2 e 4 sec. TWT) corrispondono a unità di basamento Pennidico (falde) separate da livelli di sedimenti Mesozoici e/o da ofioliti;
- alla base del Complesso Sudalpino, un riflettore molto persistente (tra 4 e 6 sec. TWT) viene interpretato come una superficie di scorrimento basale (sole thrust), all'interno della crosta continentale superiore Adriatica; questo scorrimento viene collegato ipoteticamente al sistema di splays del "Milano belt";
- al di sopra di questo scorrimento basale, una serie di riflettori in gran parte inclinati a nord confermano lo stile tettonico thin-skinned a falde sud-vergenti del Complesso Sudalpino;
- nel settore settentrionale del profilo CROP-Alpi Centrali, oltre i 15 sec. TWT, si riconosce la Moho Europea debolmente inclinata a sud; essa è sul prolungamento della Moho Europea individuata nel profilo NRP20-E1, dopo un'interruzione al di sotto della pila di falde Pennidiche;
- nel settore meridionale del profilo, sciami di riflettori vengono fatti corrispondere a una Moho Adriatica sovrapposta alla Moho Europea.

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Nella sezione CROP Alpi Centrali/NRP20-E1 si riconoscono tre domini crostali al di sopra della Moho Europea: la crosta Europea a nord, il sistema Pennidi-Austridi al centro, frammenti di crosta Adriatica a sud (fig. 3). I dati sismici sopra esposti e quelli geologici tradizionali sono coerenti con una evoluzione geodinamica della catena alpina proposta schematicamente qui di seguito.

1. La subduzione della crosta oceanica sotto la placca Africana ha prodotto sul margine Europeo un prisma d'accrezione, i cui frammenti (le future falde) hanno conosciuto un'evoluzione metamorfica eo-Alpina differenziata e un generale trasporto verso nord-ovest. L'appilamento delle falde Pennidiche e Austroalpine è una delle conseguenza della subduzione.
2. Nel Complesso Sudalpino, una fase deformativa pre-Adamello rivela la presenza di movimenti sud-vergenti, opposti alla vergenza eo-Alpina.
3. L'incuneamento di crosta Adriatica alla base delle unità Pennidiche già formate porta il sistema Pennidi-Austridi nel suo insieme a raddrizzarsi e a retroscorrere sul Complesso Sudalpino, in una fase tardiva dell'orogenesi Alpina; si formano così le miloniti insubriche e i sovrascorrimenti sud-vergenti delle Alpi Meridionali.

PAROLE CHIAVE: Alpi centrali, sismica a riflessione, crosta profonda.

## 1. - INTRODUCTION

The aim of the Strategic Project "CROP Alpi Centrali", started in 1988 with the fundings of CNR (the Italian National Research Council), was to explore the deep structure of the central sector of the Alps, combining the current geological data with geophysical prospecting, to be carried out applying seismic methodologies (Vibroseis and dynamite sources) in combination with magneto-electrical and gravity surveying.

The CROP-Alpi Centrali traverse begins at the Passo dello Spluga, close to the Swiss border, and ends near Bergamo, in the northernmost part of the Po Plain, covering a length of about 113 km. The project involved a scientific partnership with the homologous Swiss project NRP20.

The transect is divided into three seismic profiles: CROP C-ALPS/a, C-ALPS/b and C-ALPS/c and /d. The profile CROP C-ALPS/a (Porlezza-Monte Generoso) is the prolongation, in the Italian territory, of seismic line S4, part of the Swiss NRP20-SOUTH and crossing the Generoso basin (Southern Alps). The CROP C-ALPS/b profile (from Passo dello Spluga to Colico) explores the Penninic and Austroalpine units and marginally the Southern Alps; it connects with the Swiss line NRP20-EAST (transect E1), which is shifted eastwards. The profile CROP C-ALPS/c and /d (from Morbegno to Bergamo) crosses the Southern Alps, from the Insubric Line up to the Po basin. The shifting between lines /b and /c and /d was necessary to overcome difficulties with the mountain ranges and existing roads and tracks in carrying out the seismic profiling (fig. 1).

The main scientific objective of the CROP Alpi Centrali transect is to reveal the crust image across the Alpine collisional chain: the CROP line crosses the major Alpine units, from the "Milano belt" (southern margin) to the Pennine units, in the core of the Alps.

The integration of the results from the Swiss transect NRP20-EAST and from the CROP Alpi Centrali, allows the construction of a complex section crossing the whole Alpine chain, from its inner parts (Po basin) to the foreland (Molasse basin). This strategic location of the Central Alps provided the opportunity to produce a case study, which would enable us to understand the geodynamic mechanisms in the formation of a collisional chain, starting from the pre-Alpine extensional regime, to the plate convergence and collision, up to the post-collisional shortening. From this point of view the profile CROP-Alpi Centrali takes into account all the major questions, including:

1) the structures inherited from the crustal extension and thinning and their role in the subsequent reactivation;
2) the evolution of the plate margins during the convergence phases;
3) the age, location and prolongation at depth of the major collisional sutures.
4) the plate wedging in the late Alpine phases.

Above all, two problems were to be dealt with during the preliminary phases of the project:

- a possible doubling of the Moho: assuming that the European Moho underthrust under the African Moho (underplating), in the sector of the Insubric Line;
- the extent of the crustal shortening involving both the basement and the sedimentary cover, in the Southern Alps.

Furthermore, the area crossed by the northern section (CROP C-ALPS/b) is located on the eastern side of the Lepontine culmination; the easterly axial plunge of this major Alpine structure favours the exposure, on a relatively narrow band, of many units, the deepest to the west and the shallowest to the east. This structural behaviour represented a further reason for the choice of the transect location, because it allows a broad control of geophysical data in the shallower levels of the Alps, extending the near-surface geological data laterally.

A Profile Team ("Gruppo di Profilo") was established to organise and carry out the Project CROP Alpi Centrali. The following geologists and

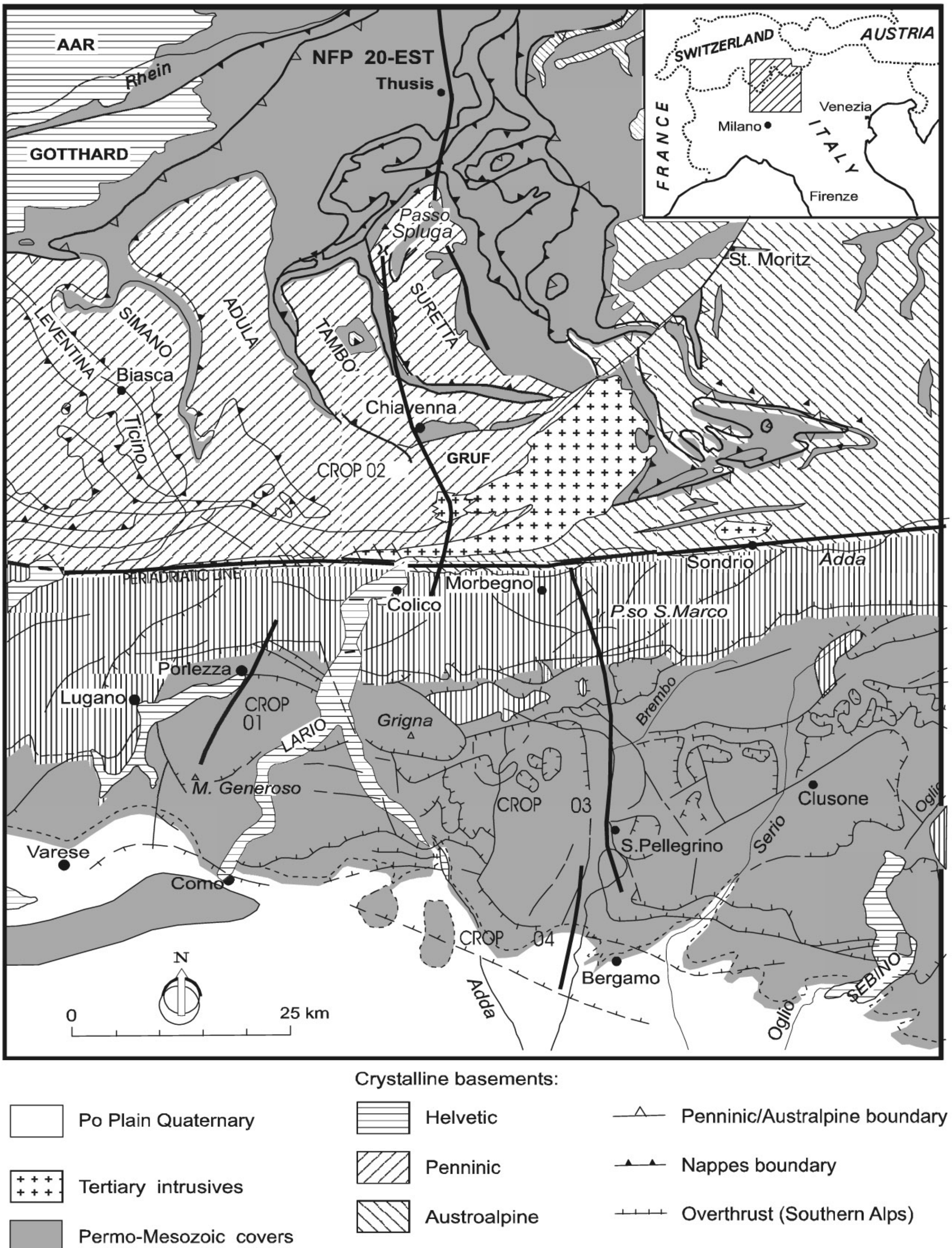


Fig. 1 – Schematic geological map with traces of the "CROP Alpi Centrali" profiles: CROP C-ALPS/a (CROP 01), C-ALPS/b (CROP 02), C-ALPS/c (CROP 03) and C-ALPS/d (CROP 04). The southern part of the Swiss profile NRP20-E1 (NFP20-EST in the figure) is also traced.

– *Carta geologica schematica, con le tracce delle sezioni del Profilo "CROP Alpi Centrali": CROP C-ALPS/a (CROP 01), C-ALPS/b (CROP 02), C-ALPS/c (CROP 03) e C-ALPS/d (CROP 04)*. E' rappresentata anche la parte più meridio*nale del Profilo Svizzero NRP20-E1 (NFP20-EST nella figura).*

geophysicists made up the Profile Team, with A. Montrasio and R. NICOLICH as coordinators.

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Further information about the organisation, realisation and interpretation of the data, are found in: CNR-CROP A.A. VARI (1989) (and ref. therein) and MONTRASIO & SCIESA (1994) (and ref. therein).

In compiling these notes the Authors took into account the volume: AA. VARI (1997).

## 2. – GEOLOGICAL SETTING

The CROP-Alpi Centrali traverse crosses four structural complexes or lineaments, briefly described in the following notes, which are intended for those who are familiar with the elements of the Alpine geology.

1) The North-Alpine nappes (Penninic and Austroalpine units). The architecture of the Penninic and Austroalpine zone, from the Penninic front to the Insubric Line, is characterized by stacked nappes, composed of basement rocks from continental crust and occasionally from subcontinental lower crust, and of Mesozoic sedimentary covers. Ophiolite slices, originated from earlier oceanic crust, highlight the transition between the Penninic and Austroalpine units. The Penninic nappes, i.e. the deeper crustal units of the outcropping alpine edifice, were affected by Alpine polyphase metamorphism, including i) an eo-Alpine, high pressure-low temperature event that occurs sporadically, ii) a widespread meso-Alpine metamorphic event, which exhibits a progradation from north-west (low grade) to south-east (high to very high grade), and iii) a late-Alpine event which significantly deformed the earlier structures. The Alpine subduction produced in all the units a widespread penetrative foliation, which was subsequently folded by post-nappes shortening, also resulting in a southward backthrust of the North-Alpine units along the Insubric mylonite belt.
   Late- to post-Alpine magmatic rocks finally intruded the Penninic units: the calc-alkaline Masino-Bregaglia (Bergel) Massif (30-32 Ma, Villa & Von Blanckenburg, 1991) and the peraluminous anatectic granite of S. Fedelino (Novate granite) (25-26 Ma: GULSON, 1973; KÖPPEL & GRÜNENFELDER, 1975; 24-25 Ma: LIATI *et alii*, 2000).
   In the sector crossed by the CROP transect, the outcropping Austroalpine units consist of a narrow belt, which thins progressively from east to west and is arranged along the Insubric mylonite belt.
2) The Insubric Line. The Insubric Line consists of a north-dipping mylonite belt. It played a major kinematic role during the neo-Alpine tectonic phase and is supposed to be connected to a south-eastward backfolding and upthrusting of the North-Alpine system (Penninic + Austroalpine nappes) over the South-Alpine block. It is represented on the Insubric mylonite belt, and possibly outlasted it. The near vertical Tonale-Centovalli Line expresses this late-kinematic and more brittle phase of deformation.
3) The South-Alpine Complex. From the Insubric Line to the "Flessura Frontale" (at the Po Plain border), the southernmost section of the traverse CROP-Alpi Centrali (CROP C-ALPS/c and C-ALPS/d) crosses the South-Alpine complex, composed of a Variscan crystalline basement (with Permo-Carboniferous clastic sediments) and a Mesozoic-Eocenic sedimentary cover. The upper crustal architecture of the South-Alpine block is mainly characterized: i) by a south-vergent overthrust of the crystalline basement roofing the Permo-Mesozoic cover (Orobic Lineament), and ii) by overthrusts and décollement nappes of Mesozoic units overriding one another. This complexity of the structure of the Southern Alps has been interpreted as a backstop response of the South-Alpine block to the compression of the North-Alpine nappes backthrusting southwards, during a late-Alpine phase.
4) From the "Flessura Frontale" to the "Milano Belt" (Southern Alps). South of the Alpine "foothills", the Mesozoic-Tertiary sedimentary sequence and its crystalline basement were involved in crustal thrusts which, at present, lie buried below the Messinian-Quaternary filling of the Po basin (PIERI & GROPPI, 1981).

## 3. – THE GEOPHYSICAL DATA

### 3.1 – SEISMIC DATA

The CROP Alpi Centrali profiles were acquired using explosive source and vibrators. Because of extremely severe financial and logistic limitations, most of the lines were acquired using explosive sources with a 100% coverage only. The complete profile CROP C-ALPS/b and a short 10 km long test segment within the profile CROP C-ALPS/c were recorded using also vibrators with a nominal coverage of 6000%.

Acquisition parameters:

Vibroseis:

| | |
|---|---|
| Recording instrument: | Sercel SN-348 and SN-368, correlator S-ICS |
| spread length: | 10 km |
| active seismic channels: | 120 with 80 m group interval |
| geophones per group: | 24, in line, 10 Hz |
| vibrators: | 4-5, 12 m spacing |
| source interval: | 80 m |
| sweep frequencies: | 10-40 Hz, 50 s length |
| sweeps per VP: | 8, patterns of 5x8, 80 m length |
| record length: | 32 s with a sampling rate of 4 ms |
| nominal fold: | 6000% |

Dynamite:

| | |
|---|---|
| number of active channels: | 120 to 192 |
| average charge size: | 97 kg |
| nominal fold: | 100% |

A split-spread geometry was adopted for the vibroseis lines with maximum offsets of 7 km. The data were acquired by OGS (main subcontractors: RIG-PRAKLA and GEOTEC).

The results obtained from the vibroseis lines clearly show that a good resolution can be achieved only if a high coverage is adopted. The large group spacing of 80 m in any case reduced the quality, because of spatial aliasing problems. Poor data were obtained also from the dynamite single fold reflection seismic in a geologically complex area with a large amount of environmental noise.

The processing was carried out at OGS and at the University of Trieste with the application of promising techniques like surface consistent residual statics, beam stearing and spectral balancing (F-X deconvolution). In the post stack processing phase dip field and coherency filters were applied.

The final line-drawing was sorted into a depth migrated model with the velocity field separated into distinct domains, suitable for the forward gravity computations. Both seismic and gravity interpretations of the CROP data took mutual advantage of the iterative use of the two different sets of data and of the need to fulfil both sets of observed data.

### 3.2. – Gravity data

New gravity data were acquired along the CROP profiles, mainly in the high mountain area with a station separation of about 1-km coinciding with a seismic trace benchmark.

This is the reason for the gap between the high-density distribution of the existing gravity stations in the Po plain (approximately 1 station/km2) and those of the alpine area (1 station/25 km2). La Coste Romberg Mod.G and Mod.D gravitymetres were used and an accuracy of 0,01 mGal was achieved. The elevation data utilized the seismic measurements with an accuracy of 0.5 m.

All the available data were processed and a map with the Bouguer anomalies was produced (2.67 g/cm3 density, terrain correction extended to 167 km, normal gravity given by the 1980 formula). The map shows a strong negative gradient from the Po plain to the north, due to crustal thickening under the Alpine chain.

The iterative interpretation of seismic and gravity data, performing the gravity modelling using original data, was based on the geometry of the seismic structures and on densities defined through the usual experimental relationship derived from seismic velocity distribution and on direct measurements of sample density performed on Penninic nappe formations. From the map of the anomalies the contribution of the Ivrea body was removed, leaving the moderate anomaly near Bergamo, linked to the structural high of the Adriatic lower crust and Moho.

The main results from the seismic/gravity modelling highlighted: the Penninic structures north of the Insubric Line; the rather complex domain of the Southern Alps; the deeper crustal structures with the presence of a dense lithospheric Adriatic wedge, forming an indenter protruding northward; the southward dipping European Lower Crust and Moho; a somewhat complex interaction between the Adriatic and European elements of the intermediate crust, not detailed by seismic or gravity data (Marson *et alii*,1994).

### 3.3. – Electrical and MT data

Sixteen magneto-telluric (MT) soundings were carried out along the CROP C-ALPS/c profile with the aim of outlining new parameters for the interpretation of the deepest structures. The MT models were correlated to the results obtained from seismic reflection, gravity and dipole-dipole geosounding data. The crystalline basement, more or less fractured or metamorphosed with the presence of plutonic bodies, was described by the conductivity values (ZAJA *et alii*, 1994).

Further MT measurements were made on top of the Penninic nappes, revealing their internal conductivity structure (ILICETO & SANTARATO, 1994).

Six geoelectrical profiles, with the Continuous Polar Dipole-Dipole method (total length about 6 km), and 34 S.E.V. were carried out exploring the outcropping area of the South-Alpine crystalline basement and its cover of Mesozoic sediments. They were used to make hypotheses about the thickness of the pile of the sedimentary rocks and to separate hidden plutonic from crystalline rocks (ALFANO, 1994).

### 3.4. – ADDITIONAL GEOPHYSICAL INFORMATION AVAILABLE FOR THE INTERPRETATION

Deep seismic sounding (DSS) data recorded within the European Geotraverse project, were carefully re-analysed with the evaluation of the s-waves velocity field and of the reflectivity images of the crust. They provided additional information on the seismic properties of rocks and on the interpretation of crust and Moho structurations on the axial part of the Alpine belt (MUSACCHIO & DE FRANCO, 1994).

Old DSS data were also reinterpreted and the regional gross crustal structure in the Central and Eastern Alpine area were examined, defining the main characteristics and the interpretation constraints of the images of the reflection seismic (SCARASCIA & CASSINIS, 1994).

## 4. – GEOLOGICAL INTERPRETATION OF THE GEOPHYSICAL DATA

In the following short notes a very concise geological interpretation of the geophysical data of the CROP Alpi Centrali transect is presented (MONTRASIO *et alii*, 1994), taking advantage of the published results of the Swiss NRP20.

In figure 2, the CROP C-ALPS/b, /c and /d line-drawing (hand produced) was matched with the NRP20-E1 line-drawing (PFIFFNER *et alii*, 1990). Some seismic marks have been highlighted on the basis of: i) lining up of reflectors, ii) well-organised swarms of reflectors, and iii) lateral interruptions of reflectors. The following seismic images were identified and geological connotation were given with varying degrees of confidence:

1a, northward overthrust of Penninic units and Ultrahelvetic slices (Penninic basal thrust), onto the External Massifs (Helvetic).

1b, northward underthrust of Penninic units beneath the Gotthard massif (PFIFFNER *et alii*, 1990, fig. 4C). The underthrust is probably responsible for the steep structures of that massif. The metamorphic pattern of the Gotthard massif is consistent with this interpretation and with its origin in the basal portion of the Aar massif.

2a and 2b,
in both line-drawing CROP C-ALPS/b and NRP20-E1, reflective intervals mark layers of Mesozoic carbonates and/or ophiolitic slices separating some basement Penninic nappes (e.g. Tambo, Adula and Simano).

3, lateral interruption of reflectors pattern, attributed to the backthrust of the Penninic-Austroalpine system over the South-Alpine block (Insubric Line).

4, can be attributed to the transition between the upper and lower European crust.

5a, transition between lower continental crust and upper mantle (European Moho) (YE & ANSORGE, 1990).

5b, southern continuation of the European Moho beneath the Adria plate wedge.

6, basal boundary of the higher crustal section of the South-Alpine block, characterised by a thin-skinned tectonic style. This basal surface can be correlated with the sole blind thrust of the foothill imbricates (CASSANO *et alii*, 1986), which can be identified with the Milano belt of LAUBSCHER (1988) or with deeper imbricates below Roeder's M.S.A.T. (ROEDER, 1990).

8, south dipping reflectors that can be linked to well-known surface faults (e.g. Antea f.); note its trend contrasting with 7, 9a and 9b.

9a, Orobic Line, a major Alpine fault marking the overthrust of South-Alpine basement onto its own Mesozoic sedimentary cover.

7 and 9b,
blind ramps of the Orobic anticline.

10, supposed boundary between the upper and lower Adriatic crust.

11a, boundary between lower continental crust and upper mantle (Adriatic Moho).

11b, assumed Adriatic Moho. The dislocation of the Adriatic Moho (11a/11b) is highly hypothetical.

12, possibly slices of Adriatic crust wedging at the base of the Penninic nappes.

13, these reflectors possibly represent a physical change of state in the Adriatic continental crust, as a consequence of post-orogenic re-equilibration processes. The good reflectivity

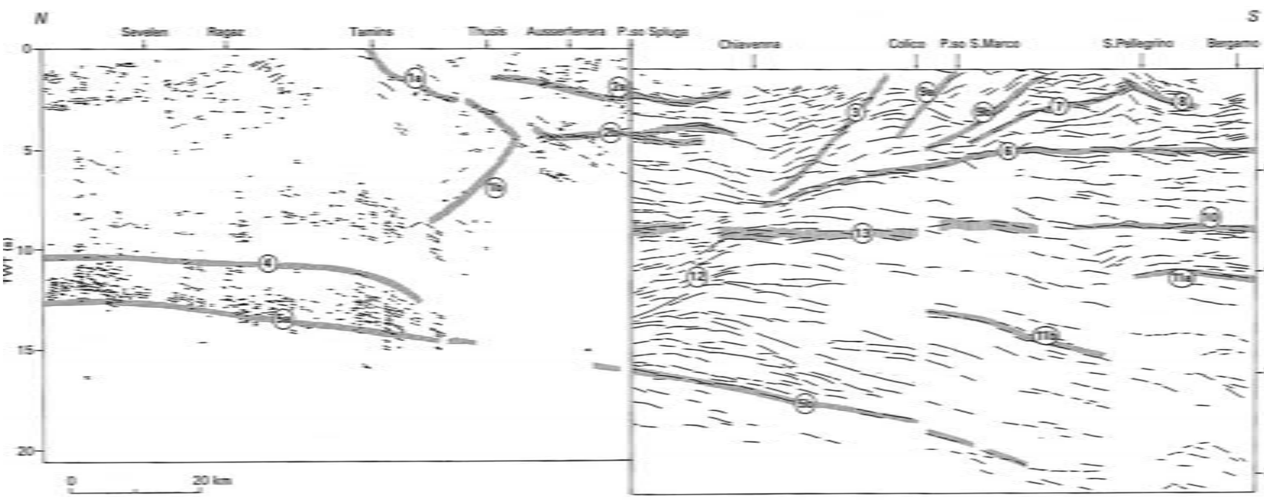

Fig. 2 – Matched line-drawings of the NRP20-E1 (left, after Pfiffner *et alii*, 1990 and CROP C-ALPS/b,/c and /d (right, after CERNOBORI & NICOLICH, 1994) seismic profiles. Explanation in the text.

– *Combinazione dei line-drawings dei profili NRP20-E1 (a sinistra, da Pfiffner et alii, 1990) e CROP C-ALPS/b,/c e /d (a destra, da* CERNOBORI *&* NICOLICH, *1994). Spiegazione nel testo.*

may be attributed to: i) layers of fluids, generated by crust degranitisation (FYFE *et alii*, 1978; HYNDMAN & SCHEARER, 1989), ii) in-situ partial melting that can be linked to anatectic processes; iii) anisotropic variations in quartz-bearing rocks, due to the Quartz-α/Quartz-ß phase transition (KHAZANEHDARI *et alii*, 1994).

## 5.– GEODYNAMIC INTERPRETATION

The following geodynamic notes are based on the above interpretation of the seismic results, integrated with the surface geology observations. Three lithospheric blocks were identified (fig. 3), corresponding, from north to south, to: European crust (EUC + ELC), Penninic-Austroalpine system (AP1-3 + PLC) and Adria crust (AC + ALC + AUC + SA).

The subduction of the Tethys ocean crust beneath the Africa plate (Upper Cretaceous - Eocene) yielded to the formation, at the European wedge, of an accretionary prism, the edges of which can be identified in units AP1-3. The HP rocks that formed in this eo-Alpine phase (130-80 Ma, HUNZIKER *et alii*, 1989), and the HP detrital minerals in the Albian Flysch (WINKLER, 1988) show that, at this time, a complete cycle in the crust (subduction, HP-metamorphism, exhumation and erosion) was already developed. The AP1 system, that is the more distal fragments of the former accretionary prism, first collided with the European continental margin. The AP1 system is composed of nappes with a different Cretaceous-Eocene metamorphic evolution and with a west-verging transport. These nappes are affected by milonite intervals (e.g. Turba milonite zone, LINIGER & NIEVERGELT, 1990) representing the beginning of the extension following the collision between the accretionary prism and the continental margin. A pre-Adamello deformation phase reveals, in the South-Alpine unit SA, a south-verging tectonic transport, suggesting a backthrust with respect to the eo-Alpine vergence.

The External Massifs and foreland (EUC), involved in north-verging compressional deformations (Lower Oligocene - Pizol phase; MILNES & PFIFFNER, 1980), and the lower crust (ELC) represent the more distal European crust. As a consequence of the crustal shortening, the North Helvetic Flysch overthrusts the north-Alpine Molasse in the Upper Oligocene (PFIFFNER, 1986).

The collision between accretionary prism and European crust had some important structural effects:

1) the vertical geometries of the External Massifs;
2) the overthrust and underthrust of the Penninic units with respect to the External Massifs;
3) the indentation between upper (EUC) and lower (ELC) European crust units. This indentation can be explained by a dragging of the upper crust by the thrusting of the Penninic units, as well as by the high ductility of the lowermost upper crust, whose temperature increased with crustal thickening;

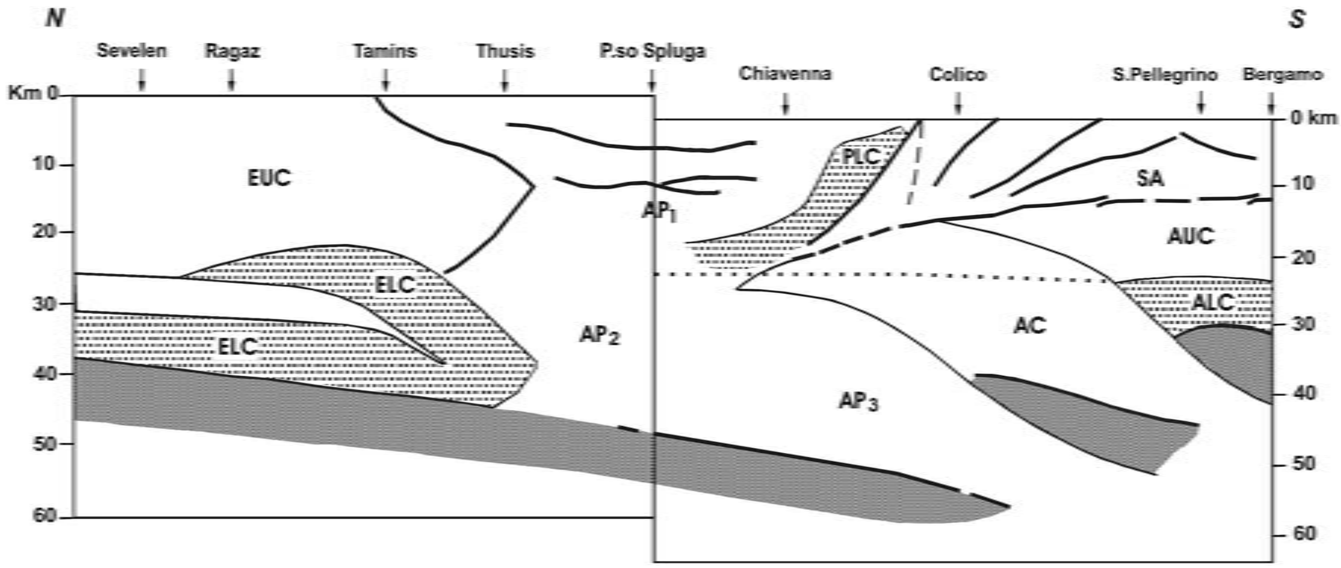


Fig. 3 – Interpretative model of the Central Alps lithospheric section, along NRP20-E1 and CROP Alpi Centrali seismic profiles. Dotted = lower crust, dark grey = upper mantle. Explanation in the text.

*– Modello interpretativo della sezione litosferica delle Alpi Centrali lungo i profili sismici NRP20-E1 e CROP Alpi Centrali. Puntinato = crosta profonda; grigio scuro = mantello superiore. Spiegazione nel testo.*

4) north-verging piling up of the Penninic and Austroalpine units;
5) continental crust thickening (piling up of the Penninic and Austroalpine nappes), resulting in a Barrowian-type metamorphism (Oligocene-Miocene);
6) wedging of the stiff Adriatic crust into the Penninic units (PFIFFNER *et alii*, 1990).

As a consequence of this wedging, the Penninic and Austroalpine units underwent a southward backthrust along the Insubric Line (SCHMID *et alii*, 1989) and a dragging up of fragments of de-granitised Penninic crust (PLC) (e.g., Gruf Complex granulites). In the Southern Alps, the backthrust resulted in a reactivation of former south-vergent structures. We can refer to this phase the thrust-fold of the pede-Alpine belt and the imbricates of the buried Milano belt; the latter were produced by the structural high of the Milano-Mortara area, NE of the Volpedo-Valle Salimbene fault (LAUBSCHER *et alii*, 1992), which acted as a buttress.

The crustal block SA represents an allochthonous portion of the Adria crust, which always had a shallow structural position during the Alpine orogeny (very low grade metamorphism). This block is cut off, at a depth of some 12 km, by a sole thrust, probably the northern continuation of the Milano belt imbricates. The Insubric Line, which was active since 18 Ma (HEITZMANN, 1987), bounds the SA block to the north. This age could be comparable with the late evolution of the Milano belt thrust system or with the "Flessura frontale" thrust (SCHÖNBORN, 1992).

The remaining structural units in figure 3 were interpreted as follows:
- AP2 e AP3 probably represent an indenter between European crust and units composed of the former accretionary prism.
- AC represents an Adria crustal wedge composed of crustal slices that experienced an Alpine tectonic evolution during the continental collision; slices of the block SA may have been peeled off from this wedge.
- ALC represents a lower crust of Adria plate; the not very deep-seated lithospheric mantle (30 km) is consistent with the gravimetric high of Bergamo (MARSON *et alii*, 1994).
- AUC represents a slice of Adria upper crust.

In conclusion, the South-Alpine upper crust unit appears to be rootless, being cut off along a basal thrust, which can be linked with the south-verging Milano belt; on the other hand, more deep Adria lithospheric elements (AC, AUC, ALC) wedge in the opposite direction, northward, into the remnants of the accretionary prism and into the European crust.

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