C. VENTURINI (*) & C. FONTANA (**)

THE NEOALPINE PHASE IN THE CARNIC ALPS: SECONDARY E-W COMPRESSIONS (***)

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ABSTRACT

This work is about the origin of a newly discovered fold and thrust system, related to the Neoalpine phase of the Carnic Alps. The axial planes of folds trend N170°-180°E and always dip low-angle. Interferences are clear with the well-known E-W trending folds, related to the N-S stage of the same compressional phase: however, from place to place, both systems re-fold each other. Here a mechanical solution is proposed, in order to connect and explain such seemingly incompatible data.

RIASSUNTO

Vengono qui per la prima volta segnalate e tentativamente interpretate le strutture tettoniche ad orientamento meridiano che recentemente sono state scoperte, uniformemente distribuite, sull'intero territorio alpino carnico. Sono rappresentate in massima parte da pieghe, da metriche a pluriettometriche, sia asimmetriche con piani assiali a debole inclinazione che simmetriche aperte, e da superfici di accavallamento rigorosamente attestati, gli uni e le altre, su direzioni N170°-180°E, con vergenze ed immersioni alternativamente verso est o verso ovest. Le pieghe N-S in certi casi ripiegano pieghe orientate E-W, in altri casi vengono da quest'ultimo sistema ripiegate. Il presente lavoro cerca di spiegare il dato motivando inoltre l'apparente anomalia rappresentata dalla presenza di pieghe orientate N-S che si sono realizzate in un campo di sforzi diretto decisamente N-S.

KEY WORDS: Eastern Southern Alps, Carnic Alps, tectonics, neoalpine phase, palaeotectonics, *Bellerophon* Fm.

PAROLE CHIAVE: Sudalpino orientale, Alpi Carniche, tettonica, fase neoalpina, paleotettonica, Fm. a *Bellerophon*.

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INTRODUCTION

During the last decade of kinematic investigations over the eastern Southern (Carnic-Julian) Alps and Pre-Alps (Fig. 1), a deformation model has been set up for the Neogene-Quaternary time lapse (VENTURINI, 1990, 1990a, 1990b, 1991): although partly derived from wide scale geological evidences, it mainly depends on detail field data (DELZOTTO, 1991; FONTANA, 1989; LAVAGNOLI, 1989; RAMBALDI, 1988; VENTURINI, 1990, 1990a).

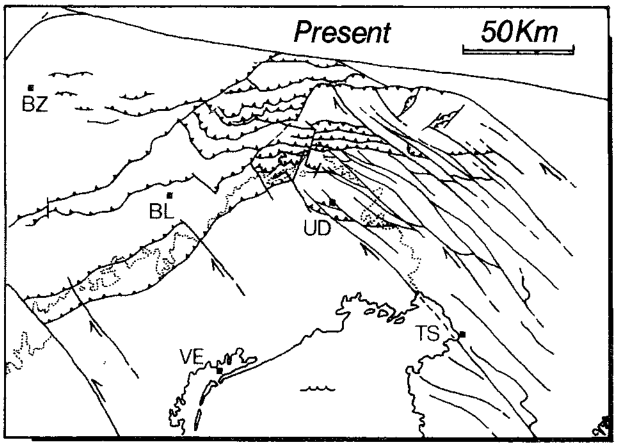

Fig. 1 - Tectonic framework of the eastern Southalpine Belt (after VENTURINI, 1991).

According to this model, the Neoalpine phase in Friuli is represented by two distinct main stress distributions: the former, N-S compression, has been active from ?Middle Miocene to ?Early Pliocene. The latter, NW-SE compression, dates Plio-Pleistocene. Tentatively, both stress fields

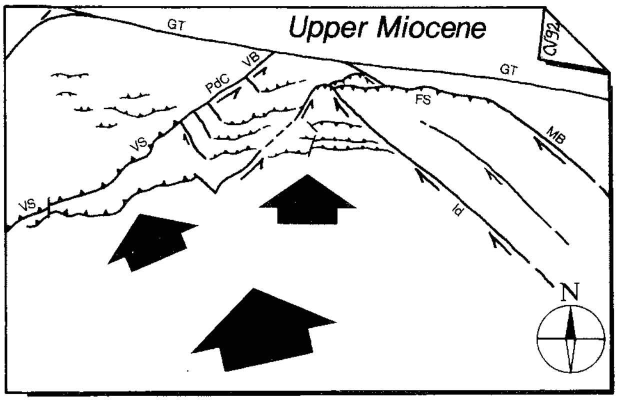

Fig. 2 - Fan-like distribution of the maxima stresses in the eastern Southalpine Belt, during the Upper Miocene. GT: Gailtal Line; VS: Valsugana Line; PdC: Pieve di Cadore Line; VB: Val Bordaglia Line; FS: Fella-Sava Line; MB: Mojstrana-Bled Line; Id: Idria Line. (After VENTURINI, 1990a, slightly modified).

may be assumed as local expressions of the same NNW-SSE trending σ1 vector (Fig. 2).

The same model (VENTURINI 1990, 1990a) concerns the re-activation, under N-S compression, of pre-orogenic Late Palaeozoic to Triassic synsedimentary faults: due to their NW-SE and NE-SW orientation, these fault systems have been given strike-slip components of motion. The indented tectonic wedges resulting from this space arrangement have been subject to deformation and consequent shortening (VENTURINI, 1990a) more than the adjoining Veneto area, where the maximum stress is about NNW-SSE since Late Miocene (DOGLIONI, 1987; CASTELLARIN *et al.*, 1992). The Carnian-Julian belt as a whole can also be seen as the near-surface deformative expression of deep crustal underthrusting from S to N (CASTELLARIN, 1979; CASTELLARIN *et al.*, 1980).

This paper will deal with the main stage of the Neoalpine phase (?Middle Miocene-Early Pliocene), as far as it concerns some interesting tectonic structures never discussed before.

THE NEOALPINE DEFORMATIONS

The Neoalpine phase of the Carnic Alps can be split in two separate deformation stages, each characterized by different maximum stress orientation.

Structures related to the N-S orientation of maximum stress are (?Middle Miocene-?Early Pliocene):

a) E-W trending folds and thrusts, associate to back-thrusts both S-facing (the most) and N-facing (the less);

b) N30°E and N140°E trending conjugate fault systems, with corresponding left-lateral and right-lateral strike-slip components;

c) N-S vertical faults, with extensional motions;

d) strike-slip re-activations of N120°E and N50°E trending ancestral faults.

Structures related to the NW-SE orientation of maximum stress are (Plio-Pleistocene):

a) NE-SW trending folds and thrusts, both SE- and NW- facing;

b) strike-slip re-activations of the previous E-W and N-S trending tectonic surfaces;

c) strike-slip re-activations (as transfer faults) of N120°E trending ancestral faults.

Scattered gentle folds trending N170°-180°E have been recently reported by DELZOTTO (1991), whereas less frequent thrusts and folds trending N-S were already known from other portions of the same belt. These data, apparently incompatible to the depicted model, have been initially regarded as local swerving from the average structure orientation.

However, further advancements in field mapping have revealed many unknown N-S trending structures. They mostly consist of both symmetric and asymmetric folds, which increase their areal frequence from the Pre-Alps to Northern Friuli. In the northern area, asymmetric folds are particularly widespread: they range in size from meters to tens of meters, just locally exceeding some hundred meters; their axial planes always dip low-angle.

The N-S fold system, till now known only E of the Val Bordaglia-Pieve di Cadore Line (Fig. 3), has often been observed to interfere with folds of the E-W system. In some cases the E-W system re-folds the N-S system, but the opposite is true for other cases. Thus, chronological relationships between the two fold systems are not definite.

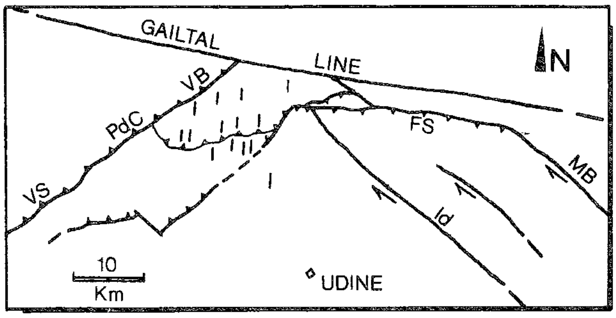

Fig. 3 - The N-S trending fold hinges (vertical bars). They are assembled inside the tectonic wedges which more suffered the shortening due to the N-S Alpine compression (?Middle Miocene-?Early Pliocene).

A tentative explanation of the apparent incompatibility of these data need further tectonic evidence to be taken into account. In the afore-mentioned deformation model of the Carnic Alps (VENTURINI 1990, 1990a), the external tectonic boundaries of the most shortened portion of the belt are represented by the Mojstrana-Bled Line (NW-SE trend, right-lateral slip) and the Val Bordaglia-Pieve di Cadore Line (NE-SW trend, left-lateral slip). These lines converge N-wards and are interrupted by the Gailtal Line (N100°E).

Over this maximum shortening area, from Forni Avoltri (close to the Val Bordaglia Line) to Tarvisio and Mojstrana (Slo), the lower member of the *Bellerophon* Fm. (Upper Permian) is characterized by thinly laminated gypsiferous sediments (Fig. 4).

On the base of new field data, here is pointed out that laminae don't derive from sedimentary processes, as suggested by VENTURINI (1990): they are due to tectonic deformation under heavy stress conditions, consequent to the Neogene compressional phase. Indeed, off the maximum shortening area, the lower member of the *Bellerophon* Fm. lacks this pervasive tectonic lamination: for instance, in the Carnic Alps 0.5 km W of the Val Bordaglia Line the stratigraphic column shows interfingering beds of black dolostone and nodular gypsum, each up to 15 cm thick (Fig. 5). Other undisturbed nodular gypsum from the lower member of the *Bellerophon* Fm. occurs in Comelico, again W of the Val Bordaglia Line.

As a consequence of the reported data, some assumptions can be drawn:

a) The laminated facies of gypsum is related to tectonic stretching and occurs just between the Val Bordaglia-Pieve di Cadore Line and the Mojstrana-Bled Line. This supports the afore-mentioned model, indicating the Val Bordaglia-Pieve di Cadore Line as the main tectonic boundary between the deeply shortened Friuli area and the less deformed Veneto area;

b) Mutual re-folding between E-W and N-S structures implies both systems being related to the same tectonic phase (Neogene compression under N-S maximum stress) Therefore, a mechanical solution is required to explain such syngenetic orthogonal folds.

Fig. 4 - Gypsiferous facies (*Bellerophon* Fm.), laminated by severe compressional tectonics. The remnants of black dolomite horizons (*cfr.* Fig. 5) appear as scattered dark fragments and gray laminae.

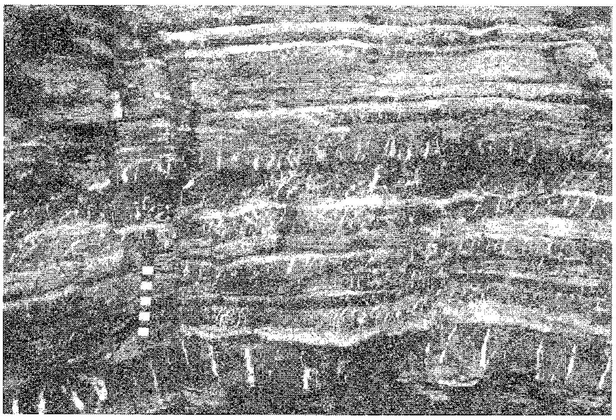

Fig. 5 - M.Chiadin. Lower Member of the *Bellerophon* Fm. Thick interbedding of nodular gypsum and black dolomite, cyclically organized. This is the first reported outcrop, over the Carnic Alps, of an almost untectonized equivalent of the gypsiferous facies dealt with in Fig. 4. Nevertheless, dolomite beds are cut by vertical calcite veins related to the Alpine compressions.

According to the kinematic model proposed for the Carnic and Julian Alps, in Friuli the development of E-W trending thrusts has been laterally constrained by the N-ward convergency of two main fault systems, respectively trending NW-SE and NE-SW: both systems have been inherited from pre-Alpine synsedimentary tectonics (Late Palaeozoic-Early Mesozoic) and strike-slip re-activated during Neogene.

In the speculative scale-model of Fig. 6a, a given volume lies on a horizontal plane and is confined between two converging N50°E and N120°E vertical planes which represent the palaeofault orientations. When a N-S oriented compressional stress is applied, pushing that volume N-wards against an obstacle, E-W trending thrust surfaces are expected to form within the sliding wedge (Fig. 6b).

However, since in the reported situation the maximum compressional stress nearly bisects the angle between the converging vertical planes, an E-W oriented component of stress must derive from the lateral constraints to the N-ward sliding of the wedge. Some E-W shortening must therefore exist (Fig. 6c), although less important than the main N-S one.

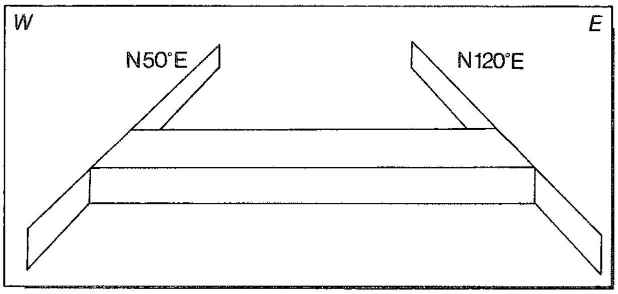

Fig. 6a -Two vertical, converging ancestral faults laterally confine a given rock volume, before the main N-S compression.

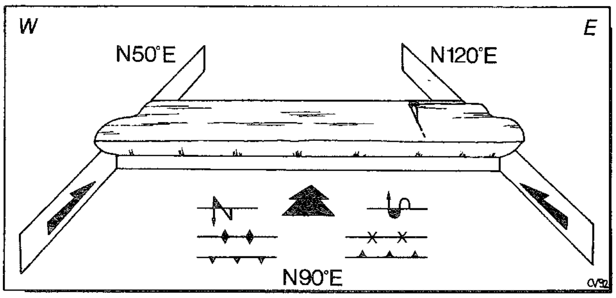

Fig. 6b - The same rock volume gets a first push N-wards. Thrusts, asymmetric folds (mostly S-facing) and gentle symmetric folds form inside. All structures trend N90°E.

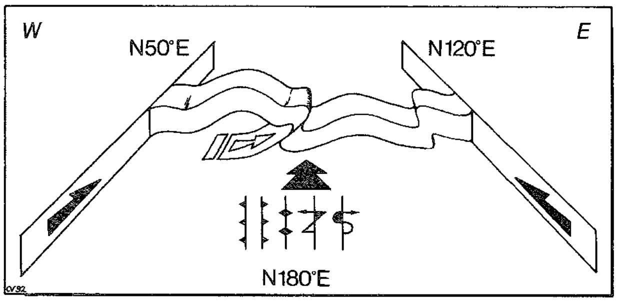

Fig. 6c - Keeping on pushing N-ward, the rock wedge furtherly shortens in a N-S direction. Subsidiary E-W contraction arises from lateral confining, by the ancestral faults. Thrusts, asymmetric folds (both E- and W-facing) and gentle symmetric folds form inside. The N-S structures interfere with the E-W ones (*cfr.* Figs. 7 and 8).

Such orthogonal simultaneous shortenings allow four possible deformation patterns:

1) In a given rock volume, the N-S stress produces E-W trending folds; then, no other deformations affect the same volume.

2) In a given rock volume, the N-S stress produces E-W trending folds; then, they are refolded by a N-S system (Fig. 7) due to the increased E-W stress component.

3) In a given rock volume, the E-W stress component produces N-S trending folds; then, if the same volume attains a suitable position, the N-S stress generates an E-W system re-folding the N-S one (Fig. 8).

4) In a given rock volume, the E-W stress component produces N-S trending folds; then, no other deformations affect the same volume.

All four cases have been recorded in outcrop.

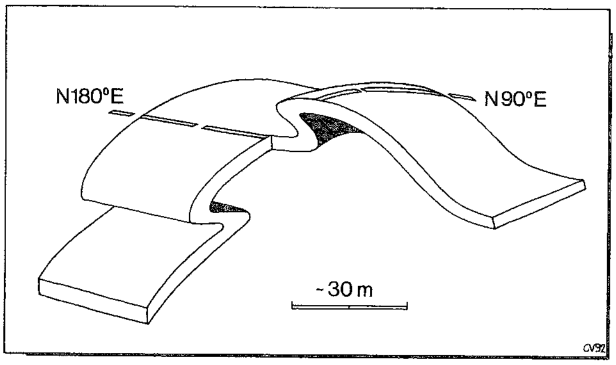

Fig. 7 - Right bank of the creek But, in front of the village Piano d'Arta, elevation 470 m. Tectonic interference within the *Bellerophon* Fm. (well-bedded limestones): an E-W trending asymmetric fold is re-folded by a N-S trending fold.

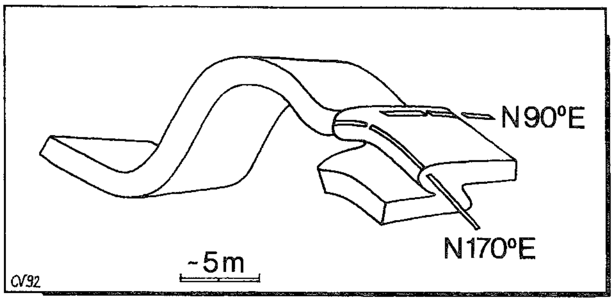

Fig. 8 - Rio Chiantone springs (Prati Palons di Noiariis), 4.5 Km W of the village Arta, elevation 1575 m along the path. Tectonic interference within the Siusi Member of the *Werfen* Fm. (thin-bedded stylolitic limestones): a N-S trending asymmetric fold is re-folded by an E-W trending one.

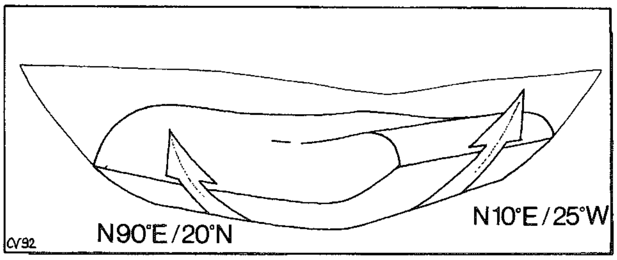

Fig. 9 - Rio Chias creek, 6 Km W of the village Zuglio, elevation 1000 m. In the outcrop along the valley-floor, the well-bedded Carnian limestones are affected by two syncronous folds, each driven by a thrust. The thrust trending N-S acts as lateral ramp for the structure trending E-W.

CONCLUSIONS

This paper is the first dedicate to the N-S trending folds and thrusts, related to Alpine tectonics in the Carnic Alps. A close connection is shown between these structures and the N-S oriented stress, responsible for the main well known E-W trending deformation pattern of the ?Middle Miocene-?Early Pliocene phase. The mechanical explanation for that has been found in two converging systems of ancestral faults (respectively trending NE-SW and NW-SE), which have been supposed to laterally constrain the N-ward motion of the wedge in between (~ 80 x 50 Km). This structure interpretation, aided by the recognition of a strongly tectonized facies in the *Bellerophon* Fm. (just over the aforementioned wedge), supports the deformation model proposed by Venturini (1990, 1990a) for the Mio-Pliocene compressional stage. Indeed the reported data, unless coming after the formulation of that model, seem to explain it.

At present, further investigations about the N-S trending tectonic structures are going on throughout the eastern Southalpine domine.

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REFERENCES

Castellarin A. (1979) - *Il problema dei raccorciamenti crostali nel Sudalpino.* Rend. Soc. Geol. It., **1**, 21-23.

Castellarin A., Frascari F. & Vai G.B. (1980) - *Problemi di interpretazione geologica profonda del Sudalpino orientale.* Rend. Soc. Geol. It., **2**, 55-60.

Castellarin A., Cantelli L., Fesce A.M., Mercier J.L., Picotti V., Pini G.A., Prosser G. & Selli L. (1992) - *Alpine compressional tectonics in the Southern Alps. Relationships with the N-Apennines.* Ann. Tect., **VI**(1), 62-94.

Delzotto S. (1990) - *Rilevamento ed analisi tettonica dell'area di Forni Avoltri (Alpi Carniche).* Tesi inedita, Univ. di Bologna, Dipart. Sc. Geol., pp. 97.

Doglioni C. (1987) - *Tectonics in the Dolomites (Southern Alps, Northern Italy).* Journ. Struct. Geol., **9**(2), 181-193.

Fontana C. (1989) - *Analisi meso- e macrostrutturale del Nucleo Paleocarnico centrale.* Tesi inedita, Univ. di Bologna, Dipart. Sc. Geol., pp. 98.

Lavagnoli A. (1989) - *Rilevamento geologico ed evoluzione tettonica dei settori di Meduno e Travesio (Prealpi Friulane).* Tesi inedita, Univ. di Bologna, Dipart. Sc. Geol., pp. 139.

Rambaldi A. (1988) - *Rilevamento ed analisi tettonica delle zone di Castelnuovo, Ragogna ed Osoppo (Prealpi Friulane).* Tesi inedita, Univ. di Bologna, Dipart. Sc. Geol., pp. 161.

Venturini C. (1990) - *Geologia delle Alpi Carniche centro orientali.* Mus. Friul. St. Nat., Pubbl. **36**, 1-222.

Venturini C. (1990a) - *Cinematica neogenico-quaternaria del Sudalpino orientale (settore friulano).* In: M. Boccaletti, G. Deiana & G. Papani (a cura di), Neogene thrust tectonics: esempi da Alpi, Appennini e Sicilia. Studi Geol. Camerti, Vol. Spec., 109-116.

Venturini C. (1990b) - *Evoluzione tettonica neogenico-quaternaria del settore alpino friulano.* In: M. Bernini & G. Papani (a cura di), Neogene thrust tectonics: esempi da Alpi, Appennini e Sicilia. 35-39.

Venturini C. (1991) - *Introduction to the geology of the Pramollo Basin (Carnic Alps) and its surroundings.* In: C. Venturini (Ed.), Workshop Proceedings on Tectonics and Stratigraphy of the Pramollo Basin (Carnic Alps), **53** (1), 13-48.

Venturini C. & Delzotto S. (1993) - *Evoluzione deformativa delle Alpi Carniche centro occidentali: paleotettonica e tettonica neoalpina.* Studi Geol. Camerti, Vol. Spec., progettazione Profilo CROP 1-1A. Questo volume.