Zusammenfassung

Die eo- und mesoalpine Tektonik in den Südalpen ist strukturell und stratigraphisch erkennbar und von den bekannten neoalpinischen Bewegungsbildern deutlich zu unterscheiden.

Die eoalpine Phase (Obere Kreide) entspricht einer N-S Kompression, die sich in den zentralen bis westlichen Südalpen bemerkbar macht. Im westlichen Bereich treten Überschiebungen auf, das Judikarische Gebiet wird hingegen durch die von links lateralen Transpressionen bewirkten Verwerfungsbündeln gekennzeichnet, die auch die altersgleichen Flysch-Ablagerungen kontrollieren. Diese tektonische Phase ist bis zum Eozän aktiv.


Die neoalpine Tektonik vererberte die eo-mesoalpindischen Gefüge-Elemente und verursachte im wesentlichen den gegenwärtig erkennbaren Gefügeplan der Südalpen.

Abstract

According to structural and stratigraphic data, eoalpine and mesoalpine tectonics can be clearly recognized in the Southern Alps and distinguished from the better known neoalpine deformation.

The eoalpine phase (Late Cretaceous) was generated by N-S compression. It deformed basically the central western Southern Alps producing overthrusts to the west and flower structures by sinistral transpression in the Giudicarie Belt. Deposition of the coeval flysch successions was controlled by the trend of this belt. This tectonic pattern persisted until Middle Eocene.

The mesoalpine phase (Eocene) was generated mainly by a ENE-WSW compression and produced thrust geometries with N-S or NW-SE direction in the eastern part of the Southern Alps. The coeval Eocene Flysch also followed this trend, filling the foredeep basin. This deformation is considered to be the front of the Dinarids, which began to be deformed since Late Cretaceous until at least Early Oligocene.

The neoalpine tectonics inherited the eoalpine and mesoalpine structures and produced the major part of the deformation accounting for the present structural framework of the Southern Alps.

Résumé

Dans les Alpes Méridionales, des données stratigraphiques et structurales permettent de reconnaitre les tectoniques éoalpine et mésoalpine et de les distinguer des déformations néoalpines, mieux connues.

La phase éoalpine (Crétacé supérieur) a été engendrée par une compression N-S. Celle-ci a affecté surtout la partie centre-occidentale des Alpes Méridionales en produisant des charriages à l’ouest et des structures de décrochement sénestres dans la chaîne des Giudicarie, dont l’orientation a déterminé la sédimentation du flysch concommitant. Cette tectonique s’est poursuivie jusqu’à l’Éocène.

La phase mésoalpine a été engendrée surtout par une compression ENE-WSW; elle a produit, dans la partie est des Alpes Méridionales, des charriages de direction N-S à NW-SE. Le flysch écène a suivi cet alignement structural, en remplissant le bassin de l’avant-fosse. Cette déformation est considérée comme le front des Dinarides, dont la formation a commencé dès le Crétacé supérieur.

La tectonique néoalpine a hérité des structures éoalpines et mésopalmes et est responsable de la plus grande partie de la structure actuelle des Alpes Méridionales.

Краткое содержание

Эо- и мезоальпийские тектонические единицы Южных Альп ярко отличаются, как в структурном, так и в стратиграфическом отношении от современных неоальпийских структурных единиц.

Во время эоальпийской фазы (верхний мел) в центральной и западной части Южных Альп протекало сдавление с севера на юг. При этом, в западной части образовались надвиги, а в южнокарском регионе — сбросы в результате боковых сдавлений, что привело к образованию асимметричных складок и флиша того же возраста. Эти тектонические процессы продолжались вплоть до эоцена.

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В мезоалльпийской фазе (эоцен) происходило сжатие в направлениях с ЕВИ до ВСВ; это вызвало в вос точных Южных Альпах образование надвигов, простирывающихся с Н - С до НВ - SE направлениями. В до-океанских бассейнах той же ориентации появляется флиш эоценового возраста. Начиная с верхнего мела появляются деформационные структурные единицы в лобовой части Динарид. Тектонические процессы, протекавшие в неоалльпийское время, унаследовали описанные выше эо- и мезоалльпийские структурные единицы и преобразовали их до наблюдаемого сегодня строения Южных Альп.

Introduction

The Southern Alps are a major structural subdivision of the Alpine Chain located by definition to the south of the Insubric Lineament (Fig. 1) and considered, according to their structural style, a S-vergent thrust-belt (De Sitter & De Sitter Koomeans 1949, De Jong 1967, Castellarin 1979, Gaetani & Jadoul 1979, Laubscher 1985, Doglioni & Castellarin 1985). However, their present structure is the product of several tectonic phases having different timing, strike and geodynamic significance.

As is well-known (see Winterer & Bosellini 1981 for a recent review), during Mesozoic times the Southern Alps experienced a long history of rifting and subsidence which set up NNE-SSW trending »highs« and »lows«. This inherited structural grain and especially the so-called Trento (or Etsch) Platform, greatly influenced the subsequent Alpine tec-

tonics (Bosellini 1965). In fact, the famous Giudicarie Belt is related to the rheologic boundary between two major paleogeographic and paleostructural domains, the Trento Platform to the east and the Lombard Basin to the west, Fig. 2 (Castellarin & Sartori 1983). The complex collision between Europe and the Adria Plate (or African Promontory of other authors) generated the Alpine Chain during three main discrete phases i.e. eocain (Late Cre taceous), mesoalpine (Paleogene), and eolpine (Neogene), (Trumey 1973, 1982, Dal Piaz et al. 1972, Laubscher 1974, Milnes 1978, Platt 1986). The thrust belt geometries of the Southern Alps also appear to be related to the above mentioned tec-

Fig. 1. Location map of the Southern Alps within the Alpine realm.

Fig. 2. The Giudicarie Belt at the hinge zone of two major Mesozoic structural elements: the Lombard Basin to the west and the Trento Platform to the east (Bosellini 1965, Castellarin & Sartori 1983). Liassic normal faults (e.g. M. Cornello, see Fig. 6), related to the Mesozoic rifting, have been involved in the sinistral transpression along the Giudicarie Belt.

The purpose of this paper is to suggest a new interpretation of the structural evolution of the Southern Alps during eocline (Late Cretaceous) and mesoalpine (Paleogene) times. What we present here is the result both of our new observations and field data and of a careful review of the existing literature.

The Eocline Event: Stratigraphic Evidence

It has long been known that the Upper Cretaceous of the Southern Alps is represented by quite distinct sedimentary successions (Venzo 1954, Ferasin 1958, Aubouin et al. 1970, Massari & Medizza 1973, Castellarin 1976, Bosellini et al. 1978, Bichsel & Häring 1981, Gelati et al. 1982). They include (Fig. 8):
1) the shallow water carbonates of the Friuli Platform;
2) the periplatform apron rich in gravity-displaced deposits;
3) the hemipelagic successions (Scaglia Rossa, Scaglia Variegata, Scaglia Grigia) of the base of the slope and of the deeper water plateaux, starved structural highs and distal basinial areas;
4) a composite clastic wedge of terrigenous turbidites (Varesotto Flysch, Sarnico Sandstone, Bergamo Flysch, Insubric Flysch) of Turonian-Campanian age, with an aggregate thickness of up to 2000 m, having its depocenter in the Bergamo area, between the lakes of Iseo and Como.

Aptian-Albian flysch near Cortina (Scudeller Baccelle & Semenza 1974) and the marly hemipelagic character of the Cretaceous sediments outcropping in several areas of the Dolomites (Sella Group, Puez Group, La Stua near Cortina, etc.), suggest the possible occurrence of another submarine fan system to the north of the Dolomites during Late Cretaceous time.

Terrigenous turbidites of northeastern provenance, began to replace the hemipelagic sedimentation over most of the Lombard Basin in the Late Cenomanian. The westward progradation of the submarine fan system is documented by paleocurrent data (Bichsel & Häring 1981, Gelati et al. 1982).

To the west, the Varesotto flysch starts with channelized deposits containing large amounts of Upper Cretaceous shallow-water debris, probably derived from a shoal or shelf edge situated to the north Bichsel & Häring 1981). The Bergamo Flysch accumulated in Late Santonian-Campanian times as a monotonous outer fan association all over the Ber-
Giudicarie Belt and have been interpreted as old Miocene canyons (Bint et al. 1978).

The southern margin of the foredeep basin is documented by the 300 m thick Scaglia of the Malossa Field, near Milan, which represents the whole Cretaceous. Possibly, it was deposited on a sort of peripheral bulge (sensu Quinlan & Beaumont 1984), rising diachronously in front of the migrating foredeep basin.

The Eoalpine Event: Structural Evidence

The E-W or ENE-WSW S-verging overthrusts of the Bergamasc and Bresciane Alps (De Sitter & De Sitter Koomans 1949, Gaetani & Jadoul 1979, Cassinis 1982, Brack 1981, 1984) to the west of the Giudicarie Belt and the buried overthrusts of the Po Plain to the south of the Bergamasc Alps (Pieri & Groppi 1981) enter the Giudicarie Belt, gradually changing their strike to a NNE-SSW direction and their geometry along the west side of the Garda Lake into an oblique ramp, finally acquiring lateral ramp and flower structure geometries in the Giudicarie Belt. Here, they show E or ESE vergence, while the NNE-SSW striking faults often have a subvertical attitude and are arranged in positive or negative flower structures (sensu Harding 1985); see the cross sections of Trevisan (1939, 1941), Vecchia (1957), Castellarin & Gatto (1981), and Castellarin & Sartori (1980, 1982) as examples. Therefore, the overthrusts of the Bergamasc and Bresciane Alps appear to pass into the Giudicarie Belt as lateral ramps or transpressive faults (Fig. 3). Several low-angle NNE-trending thrusts also occur within the Giudicarie Belt and conjugate strike-slip faults (dextral N80E and sinistral N40W) displaying a local sigma 1 of about N70W direction. The main geometries of the belt and their connections with the Bergamasc Alps support the notion of an important sinistral transpressive movement along the Giudicarie Belt itself, more than suggested by the left-lateral displacement of the Insubric Lineament between the Pustertal and Tonale segments. Geometries similar to the arc of the Bergamasc Alps – Giudicarie Belt occur, for instance, along the Chaman Transform Zone at the Pakistan-Afghanistan boundary (Lawrence et al. 1981) and in minor faults of the Jura (Laubscher 1972), regions for which sinistral transpression has been demonstrated. Several horizontal striations along the Giudicarie Line (e.g. Pieve di Bono, Roncone) support a sinistral strike-slip motion along this fault. Striations and Riedel wedges also point out normal movements in the southern part of the Giudicarie Line (Castellarin & Sartori 1982), but they could be related to the emplacement of the Alpine Adamello intrusion (Brack 1983).

The amount of sinistral strike slip displacement along the Giudicarie Belt is a function of the shortening of the western Southern Alps with respect to the eastern Southern Alps; the shortening has been calculated as at least 40–60 km (Laubscher 1985) along the Grigna Group, but it could well be of 80–90 km if we take into account the entire section of the Lombard Alps. In the eastern Southern Alps, the conser-

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**Fig. 3.** The gradual transition from frontal ramp overthrusts in the Bergamasc Alps to oblique ramp and finally to lateral ramp overthrusts and flower structures in the Giudicarie proper. This structural setting can be clearly appreciated when observing the cross sections of the pertinent areas, e.g. Laubscher (1985) for the Bergamasc Alps and Trevisan (1939) for the Giudicarie.
vative shortening is instead estimated at only 30–40 km (Doglioni & Castellarin 1985) suggesting a different tectonic evolution of this eastern sector compared to the western one.

As described above, there is a clear structural connection between the Bergamasc Alps and the Giudicarie Belt (Fig. 3). The problem is to date the tectonic events. We know from the Bresciane Alps that there is an important tectonic phase that predates the Adamello intrusion (De Sitter & De Sitter Koornans 1949): in fact, several intrusions of the batholith (42–30 m.y. old, Late Eocene-Early Oligocene, Del Moro et al. 1983) cut preexisting ENE-WSW trending large-scale folds of Triassic carbonates (Brack 1981, 1984). These pre-Late Eocene tectonics do not continue eastward into the Dolomites; for this reason, Doglioni (1987a) supposed that the pre-Adamello tectonics of the Bresciane Alps might have passed laterally into the transpressive system of the Giudicarie Belt (Fig. 4). According to this interpretation, we must expect to find the appropriate stratigraphic documentation of these pre-Upper Eocene tectonics within the Giudicarie Belt itself. Castellarin (1976) observed that the Cretaceous flysch distribution follows the arc formed by the Bergamasc Alps and the Giudicarie Belt in the central-western Southern Alps. If we agree with the syntectonic concept of the flysch deposits, we can expect that the Cretaceous flysch of the western Southern Alps accumulated just south of an active S-vergent thrust-belt. The arcuate shape of the flysch basin also supports an arcuate shape of the source area, which could in fact have been the former tectonic arc of the Bergamasc Alps and the Giudicarie Belt. Turonian unconformities (Fuganti 1964) are very common within the Giudicarie Belt, and they have been interpreted as big submarine slump scars (Castellarin 1972). Fuganti (1964) suggests Turonian tectonics within the Giudicarie Belt while Bosellini et al. (1978) have documented the rising in late Cretaceous time of narrow and elongated basins and horsts bounded by reverse faults with the typical Giudicarie strike (NNE-SSW). An Eocene deformation phase has also been supposed within the Giudicarie system (Fig. 5) to explain different facies and deeply incised unconformity surfaces (Bosellini & Luciani 1985, Luciani 1987).

Certainly, the Neogene tectonics of the Southern Alps strongly overprinted the structures of both the Bergamasc Alps and the Giudicarie Belt. This has been documented by Cassinis & Castellarin (1981), Castellarin & Gatto (1981), Pieri & Groppi (1981), Castellarin & Sartori (1982, 1983). Apparently, from the fold axis and the overthrust trends, the pre-Upper Eocene sigma 1 of the Southern Alps had the same direction of the Neogene sigma I (about N25W), with local gradual changing as far as N70°W in the Giudicarie Belt for the compressive vector of the transpression.

The Giudicarie Belt has always been essential for a clear understanding of the structural evolution of the Southern Alps, and several important analytical

Fig. 4. The age of the Adamello batholith ranges from 42 to 30 m.y. (Del Moro et al. 1983), with the oldest ages (40–42 m.y.) observed in the little gabbro bodies in the southern part of the intrusion, where Brack (1981, 1984) has shown a pre-batholith compressive tectonic phase. While these pre-Late Eocene tectonics probably extend into the western Bergamasc Alps (Laubscher 1985) and in the Orobie Alps (Cassinis et al. 1986), they are apparently missing to the east, for example in the Dolomites (Doglioni 1987). As they cannot stop suddenly, they must enter the Giudicarie Belt changing progressively into transpressive structures (note the arrows). This statement is supported by the observed transition (frontal ramp to flower structures), the layout of the Cretaceous flysch and the Late Cretaceous unconformities within the Giudicarie Belt. See also Fig. 5.
Fig. 5. The M. Baldo positive flower structure as an example of Eocene tectonics in the Giudicarie Belt. This high, active since Late Cretaceous (see unconformity at the base of the Scaglia Rossa) underwent a major uplift during Early Eocene: note the unconformity at the base of the Calcare di Torbole and the buried faults (after Bosellini & Luciani 1985). The deep fault trends are inferred (from Luciani 1987).


The interpretative problem is the origin of the apparent sinistral displacement of the Insubric Lineament along the Giudicarie Line (Fig. 1). In fact, Trevisan (1939) suggested a sinistral strike-slip motion of the Giudicarie Line to explain both the observed structural pattern and the abrupt facies changes; many other authors agreed with this interpretation. However, Vecchia (1957), Castellarin & Sartori (1980, 1982, 1983) believe that a very small horizontal displacement occurred along the line during Neogene times. Moreover, they point out that the emplacement of the Giudicarie Line was controlled by the inherited hinge between two Mesozoic structural and paleogeographic domains, the Trento Platform to the east and the Lombard Basin to the west (Bosellini 1965). Fig. 6 is an example of a Liassic growth fault, located along the edge of the Trento Platform. It is a listric antithetic normal fault which allowed a thicker succession of Calcari Grigi in the eastern hangingwall. The Liassic fault was later involved in the alpine deformation and is located in a limb of a fold of the Giudicarie system.

We maintain that the location of the Giudicarie Belt is related to an inherited structural grain. This structural pattern requires a sinistral transpressive mechanism of Late Cretaceous – Paleogene p.p. age to be consistent with the observed structural data.

The structural analysis of the whole Southern Alps with the construction of balanced cross-sections allows us to subdivide the Southern Alps in sectors with different amounts of shortening, different strike and different age of deformation. As pointed out by Castellarin (1984), during the Alpine deformation, the Southern Alps underwent a pre-Miocene tectonic phase, an Upper Miocene tectonic phase and a last Pliocene-Quaternary tectonic phase which is still active in the central-east Southern Alps. We tried to construct a restored tectonic map of pre-Upper Miocene tectonics (Fig. 7) with the help of the minimum shortening of the Neogene age extrapolated by the balanced cross-sections: it appears that the western Southern Alps were already narrower than the eastern Southern Alps in pre-Upper Miocene times and that the Giudicarie Belt was the transition zone between two different domains of shortening (greater to the west). The zone was not a single fault line, but a system of subparallel lines with the same strike of the main line. The Giudicarie Belt
is localized roughly at the boundary between two major N-S (or NNE-SSW) trending Permo-Mesozoic structural elements (Trento Platform and Lombard Basin), but the alpine deformation strongly affected the internal parts of the two domains as well.

In our view, the active Late Cretaceous–Paleogene p.p. tectonic arc (Bergamasc Alps – Giudicarie Belt) was located some tens of km to the north of the present position. Later, the Neogene tectonics displaced and reactivated the entire arc toward the south, producing new overthrusts in the western sector, juxtaposed to flower structures and en-echelon overthrusts in the Giudicarie Belt.

In conclusion, a gradual transition from thrust geometries in the Bergamasc Alps (Laubscher 1985) to oblique ramps northwest of the Garda Lake, and, finally, to lateral ramps and flower structures in the Giudicarie proper can be clearly recognized in the
Fig. 7. If we try to restore the area of the Southern Alps on the basis of the shortening calculated with balanced cross-sections, a larger retrodeformation of the western sector with respect to the eastern one is necessary. This demands a pre-alpine larger area for the western Southern Alps, later shortened in pre-Neogene times. The pre-Neogene structural setting was inherited by later tectonics (see map of the present situation). These restored maps are a first attempt to reconstruct the retrodeformation of the Southern Alps: they are empiric and need further improvements.
Southern Alps. In conclusion, we interpret part of this structural setting as due to a N-S compression of Late Cretaceous – Paleogene p.p. age, which produced E-W trending thrust geometries in the Bergamasco Alps and related sinistral transpressive accommodation movements in the Giudicarie Belt, where NNE-SSW trending flower structures are clearly recognizable.

The Neogene compression inherited and reactivated these earlier tectonics.

We tried to plot the Late Turonian paleogeography on the pre-Miocene restored tectonic map of Fig. 7; the result is presented in Fig. 8; Figs. 9 and 10 are two hypothetic cross-sections of that time.

This eolalpine tectonic phase of the Southern Alps is most probably correlated with the well known eolalpine event of the Alps s.s., (Dal Piaz et al. 1972, Müller 1973, Hunziker 1974, Dietrich 1976, Trümpy 1973, 1975, 1982, Thöni, M. 1980, Laubscher & Bernoulli 1982). The Devonian phase of the Gosau phase (Müller 1973, Oberhauser 1968) show clearly compressional tectonic activity during Late Cretaceous times, while Late Turonian sandstones of the South-Penninic Flysch contain high-P/low-T minerals, suggesting an Early-Middle Cretaceous age (128 m.y., Dal Piaz et al. 1978) for the subduction of the Tethyan Ocean (Winkler & Bernoulli 1986). The Austroalpine (e.g. Dal Piaz 1937) underwent eolalpine deformation and metamorphism (Flügel 1987, Tollmann 1987), probably linked to the same geodynamic event that deformed the Southern Alps during this time.

The Mesoalpine Event: Stratigraphic Evidence

The eastern Southern Alps (from Feltre eastward) and the adjacent part of the Dinarids are typically characterized by the occurrence of the Friuli Flysch,
a thick (up to 1000 m) and composite clastic wedge which progressively encroaches on the former Late Cretaceous and Paleocene paleogeographic domains, i.e. a deep-water basin to the north (Scaglia) and a rudist carbonate platform to the south (Friuli Platform). Consequently, the timing of the flysch onset varies from Paleocene (NE) to Late Lutetian (SW) (Cousin 1981). The flysch «transgression», however, was not continuous but occurred during discrete steps, in Middle Ilerdian, Middle-Late Cusian and Bariatrizian times.

The Friuli Flysch is represented by very coarse facies to the east such as olistostromes, debris flows and turbidites of exceptional volume, (Gnaccolini 1968, Venco & Brambati 1969), which grade westward into more distal facies and finally to the basin plain deposits of the Alpago and Belluno valleys. Paleocurrent data (Sarti 1979) clearly show a N or NW provenance, while the abundance of metamorphic and igneous quartz grains suggests a stratigraphically deep source for the siliciclastic component. The Eocene Flysch lies discordantly on the underlying folded Maastrichtian flysch near the Italian-Yugoslavian border (Natisone Valley). These stratigraphic relationships confirm that the Late Cretaceous orogenic phase also affected the Dinarids. To the SW, the substratum of the Ilerdian flysch is represented by the Maastrichtian Scaglia and finally by the rudist carbonate platform. The Scaglia also appears first to the east and onlaps the gently folded Friuli Platform which probably contains structures with Dinaric strike (Cousin 1981).

The common megabreccias, (the so-called «conglomerati pseudocretacei» auct.) occurring in the proximal flysch, derive from source areas immediately to the north and northwest, where a Paleocene-Eocene uplift had exposed the entire Mesozoic carbonate succession to erosion (Sarti 1979).

At Monte Sompave and Monte Amariana (confluence Tagliamento-Fella), Lower-Middle Lutetian nummulitic limestones lie discordantly on the Dachstein Kalk of Late Triassic age. Also in the Dolomites, at Monte Parei northwest of Cortina, a Late Oligocene – Early Miocene marine conglomerate (probably a beach deposit) overlies the strongly folded Liassic limestones (Cros 1978, Doglioni 1985).

Another interesting piece of information is provided by the Friuli Platform during Paleocene-Eocene times. First it was gently folded, uplifted with local formation of bauxite horizons. Then, while outer shelf foraminiferal (alveolinids, nummulitids, discocyclinids) limestones «colonized» the top of the Cretaceous platform, it collapsed along step faults, locally releasing megabreccias, and finally, it was buried by the turbidites. It is a kind of tectonic «yo-yoing», clearly documented all over the Friuli Platform (Cousin 1981). We believe the above described behavior can be interpreted as the response of the lithosphere to the load created by the Dinaric thrust pile. This model shows the creation of a downwarped flexural moat (foreland or foredeep basin) around the load with this moat in turn surrounded by an upwarded peripheral bulge (Quinlan & Beaumont 1984). As both the bulge and the moat migrate laterally with the advancing thrust front, our platform must have sunk after the initial uplift. In the remaining Venetian Alps and in the Po Plain (Fig. 14), the Middle Eocene is characterized mainly by hemipelagic sediments (Scaglia Variegata, Scaglia Grigia, Scaglia Cinerea, Marne Euganeee, Argille di Ponte Arche, etc.). Only two shallow water banks were still
present during this time, the Verona Platform with islands and volcanoes, and the M. Baldo reeal tract, an inheritance of the Late Cretaceous, probably still active strike-slip tectonics.

The Mesoalpine Event: Structural Evidence

The main evidence for a mesoalpine compressional phase (e.g. Trümpy 1973) can be found in the eastern Southern Alps, i.e. in the Dolomites and in Friuli. The presence of Dinaric structures in eastern Friuli has been recognized for many years (Winkler 1923–1936).

Compressive structures (overthrusts and folds) WSW-verging with Dinaric strike (N20–50°W) have also been widely documented in Friuli by Dainelli (1921), Selli (1963), Martinis (1966–1975), Carobene et al. (1981), Cavallin (1981), Frascari & Vai (1981), Slejko et al. (1986).

These NW-SE (or N-S) trending structures have been generally interpreted as older than the Neogene E-W trending overthrusts of eastern Friuli (Selli 1947, Cousin 1981).

Structures of pre-Neogene age with a Dinaric trend have also been observed in the Dolomites (Cousin 1981, Doglioni 1985). The timing of these geometries is constrained by an Upper Oligocene-Lower Miocene conglomerate at Monte Parei (Cros 1966, 1978) which lies unconformably on folded rocks. Thus, the front of the WSW-verging Dinaric Chain reached the central Dolomites, but its overthrusts have been faulted and folded by the Neogene S-verging deformation (Doglioni 1987a). In the Venetian Alps, superimposed tectonic phases have also been observed (Stephan 1973), and a connection of the NW–SE trending structures with the overthrusts of the front of the Dinaric Chain to the SE can be inferred (Doglioni 1987b). Cousin (1981) and Doglioni (1987a) suggest a Paleogene age for the Dinaric structures present in the eastern Southern Alps. This statement is in agreement with structural and stratigraphic data: a) the Neogene deformations are younger than the NW–SE trending folds and overthrusts, which in turn affect Cretaceous sediments, and b) the Paleogene Flysch of the eastern Southern Alps has Dinaric provenance and areal distribution (Fig. 14). The age of the main tectonic phases of the frontal part of the Dinaric Chain is generally accepted as Paleogene (Aubouin et al. 1970, Aubouin 1973, Burchfiel 1980), but Cousin (1981) suggested a more detailed timing for this deformation, i.e. post-Lutetian / pre-Upper Oligocene.

In short, the mesoalpine structures of the eastern Southern Alps are related to the Paleogene front of the Dinaric Chain. The present boundary between Southern Alps and Dinarids is gradual; it can be placed where the NW-SE-trending structures of the Dinarids prevail over the E-W South-Alpine structures.

We propose that no single sharp boundary exists between the Dinarids and the Southern Alps. Rather, there has been an interaction in time and space of the two deformational fields during alpine times.

The main elements indicating Dinaric structures in the field are the following:
- a) the NO–50°W trending of fold-axes and thrust-planes;
- b) the N90–140°W direction of stretching lineations (i.e. striae on the thrust-planes);
- c) the general and constant W–SW-vergence of a) and b) structures;
- d) conjugate systems of subvertical strike-slip faults, dextral (N10–60°E) and sinistral (N70–120°E);
- e) All the previous structures can be found as inherited geometries within the Neogene E-W trending Southalpine deformation.

Fig. 11 is an example of a W-vergent pre-Neogene isoclinal recumbent fold in the Dolomites (M. Parei).

According to all the available data both from the literature and from our field work in the Dolomites, in the Venetian Prealps and in the Friuli regions, a continuity of the Dinaric Belt within the Southern Alps appears quite clear (Fig. 12). From the map of Fig. 12 two main conclusions can be drawn: 1) the Dinaric system extends far into the eastern part of the Southern Alps; 2) the Dinaric structures have been later affected and disrupted by the E-W trending structures of the neopaline Southern Alps. For example the Valsugana Line, the Belluno Line and the Basiano Line all displaced the front of the Dinarids.

The Paleogene Dinaric system is therefore not outside the Southern Alps (to the east), but it has been instead inherited and incorporated into that part of the Neogene S-vergent thrust-belt which constitutes the eastern Southern Alps.

The shortening generated by this tectonic phase is not clear. Only the sedimentary cover has been deformed in the Dolomites, but eastward in Friuli, the basement or the Paleozoic of the so-called «Catena Paleocarnica» could also have been involved. In the Dolomites, considered as the front of the Dinaric Chain, the conservative minimum shortening is 10 km (Doglioni 1987a), but east of the Dolomites the shortening could be as much as 30–50 km. In the pre-Paleogene restored map (Fig. 7), we tried to calculate a minimum shortening, taking into account this «Dinaric» deformation.
Fig. 11. Recumbent fold in a thrust hangingwall affecting the Jurassic limestones (Calcari Grigi) of the Dolomites (M. Parel). Note the W-vergence, typical of the Dinaric structures. This structure is the northward continuation of the Croda del Vallon Bianco – Tofana W-verging thrust sheet (DOGLIONI 1985), and it is unconformably sutured by an Early Miocene conglomerate.

Fig. 12. The Dinarids front in the Southern Alps. Two important points have to be remarked: 1) the Dinaric system has strongly involved the eastern Southern Alps before their Neogene deformation, note the area of overlapping; 2) the Dinaric front has been segmented and thrusted by the following S-verging Southalpine Neogene tectonics.

The superposition of two belts (Dinarids and Southern Alps), having different, almost perpendicular strikes, generated very complicated geometries which can be deciphered only with a three-dimensional restoration of the structures. Two-dimensional cross-sections are not easily retrodeformable because inherited folds and overthrusted can lead to a misunderstanding of the original situation. Moreover, the
overlapping of the two chains is a serious difficulty in calculating the true shortening of the Neogene deformation of the eastern Southern Alps which appear much more deformed than they really are.

Fig. 13 is an interpretation of two superimposed perpendicular overthrusts; this is an example which can be applied to many structures of the eastern Southern Alps.

The original shape of the Dinaric structures can be observed more easily in the core of synclines (e.g. Civetta klippe in the Dolomites or the Mangart overthrust in eastern Friuli); E-W trending Southalpine overthrusts, interpreted as Neogene in age and outcropping as lateral ramps (for instance the Antelao Line in the Dolomites or the Maniago Line in Friuli), are instead the frontal ramp of Dinaric WSW-vergent overthrusts later tilted or folded and subsequently eroded in a shape which leads to misunderstanding regarding their true origin. This is confirmed by structural data such as stretching lineations and fold axes along the thrust-planes.

The lithostatic load caused by the tectonic piling associated with the Dinaric phase generated a foredeep basin filled with the Eocene flysch.

The Dinaric structures still appear to be active in the Friuli foothills (Slejko et al. 1986), but in any case, the main phase of deformation is of pre-Neogene age.

N60–40W trending faults, as for example the Idria Line, have always been interpreted as Dinaric structures because of their NW-SE orientation. In our opinion and according to the general alpine Neogene stress field, with a N20–30W sigma 1, these faults can be better interpreted as neoalpine dextral strike-slip faults. A beautiful cross-section of the Idria Line, obtained from data of the Idria mine (Mlakar 1967,
Fig. 4), shows flower structures generated by the NW-SE trending Idria Line which displaced earlier thrust planes of the true Dinaric system.

The NE-SW striking Dinaric stress field usually produced NW-SE trending overtrusts and folds rather than dextral strike-slip faults with this direction.

In conclusion a superposition of two belts occurs in the eastern part of the Southern Alps: the Dinarids (in their natural NW prolongation from the eastern Adriatic sea) with a general NW-SE strike, and the Southern Alps proper with a general E-W strike.

Structural and stratigraphic data support basically a Paleogene (mesoalpine) age for the Dinaric structures and a Neogene (neoalpine) age for the Southalpine structures. The overprinting of these two tectonic trends easily leads to misunderstanding of the real geometry and the shortening linked to each belt (Dinarids and Southern Alps): the structure of the eastern Southern Alps can be restored only by considering all three dimensions.

Fig. 14 represents the Eocene (Lutetian) lithofacies and paleogeography plotted on the pre-Miocene restored map of Fig. 7. In the corresponding inter-

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**Fig. 14.** Middle Eocene (Lutetian) paleogeology of the Southern Alps drawn on the corresponding retrodeformed map (Fig. 7). Note the WSW-vergent overtrusts and the flysch deposition associated to this compressional «Dinaric» tectonic phase. A-A' is the trace of the cross-section of Fig. 15.

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**Fig. 15.** NE-SW cross-section of the Eastern Southern Alps during Eocene (Lutetian) time. Note the thrust-belt geometry and the foredeep basin generated at the front of the Dinaric Belt and filled by the coeval flysch. Section not to scale.
Fig. 16. The main compressive tectonic phases affecting the Southern Alps during "Alpine age": a) Late Cretaceous – Middle Eocene N-S compression; b) Paleogene N50–70°E compression; c) Late Oligocene – Late Miocene N0–30°W compression; d) Plio-Quaternary N0–30°W still active phase.
Conclusions

Concluding our discussion of the various tectonic phases accounting for the complex deformation of the Southern Alps, the following Alpine history can be traced:

1) A Permo-Triassic to Middle-Jurassic recurrent rifting segmented the crust of the Southern Alps into NNE-SSW trending highs and lows (Bosellini 1965, 1973, Winterer & Bosellini 1981). These rifting geometries were then inherited by the subsequent Alpine compression (Bosellini & Doglioni 1986).

2) The eoalpine (Late Cretaceous – Paleogene p.p.) deformation (sigma 1 N0–30°W) affected only the central and western parts of the Southern Alps (Fig. 16a), producing pure compression in the western sector (Bergamasco Alps) and sinistral transpression in the central sector (Giudicarie Belt), where narrow and elongated «horst and graben» structures (actually flower structures) of Late Cretaceous and Eocene age occur (Bosellini et al. 1978, Luciani 1987). The basement was strongly involved in this phase, especially in the northernmost sectors. The coeval Lombard Flysch closely follows the trend of this belt.

3) The mesoalpine (Middle Eocene – Lutetian) «Dinaric» compression (sigma 1 N50–90°E) deformed the eastern Southern Alps (Fig. 16b), generating overthrusts and folds with Dinaric direction (N0–45W). The Eocene Friuli Flysch is strictly related to the Dinaric trend and was deposited diachronously in the advancing foredeep basin. In the Dolomite region, only the sedimentary cover appears to have been involved in this compression. We believe that the Dinaric front occurs here. The basement was probably involved east of Friuli, in the Dinaric Chain proper (Yugoslavia).

4) The nealpine (Late Miocene) compression (sigma 1 N0–30°W) then affected the whole Southern Alps (Fig. 16c) involving the basement in all the main faults (e.g. Val Trompia, Orobie, Valsugana overthrusts).

5) A Plio-Quaternary phase (sigma 1 N0–30°W) is now deforming the central-eastern sector of the Southern Alps, amplifying the nealpine deformation in this area (Fig. 16d). The present seismicity documents the on-going nature of this phase.

We tried to restore the above described Alpine tectonics (Fig. 7) and used the restored maps to reconstruct the paleogeography of the Late Cretaceous (Fig. 8) and Middle Eocene (Fig. 14) times in the Southern Alps. Figs. 18a–d, summarize the above model of the structural evolution of the Southern Alps. At this stage we consider this model strictly as a working hypothesis. Notably the areal extent of eoalpine and mesoalpine tectonics contains an element of speculation and variations of the above model are conceivable. For instance, the eoalpine tectonics could continue eastward to the north of the Dolomites, and eoalpine tectonics (Maastrichtian) could also be present in the eastern Southern Alps at the Italo-Yugoslavian border (the beginning of the Dinaric deformation). Mesoalpine tectonics (Eocene) could also have been active in the central-western sector (Brack 1987). Moreover, we did not take into account other tectonic phases, e.g. the Oligocene extension (Dal Piaz 1976, Laubscher 1983) which could contribute substantially to the structural palimpsest of the Southern Alps.

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