Riv. It. Paleont. Strat.	v. 90	n. 4	pp. 545–564	Marzo 1985

SHELF–BASIN TRANSITION: SEDIMENTOLOGY AND PETROLOGY OF THE SERRAVALLIAN OF THE TERTIARY PIEDMONT BASIN (NORTHERN ITALY)

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Key–words: Serravalle Sandstone, Cassinasco Formation, Facies analysis, Sandstone petrography, Hybrid arenites, Synsedimentary tectonics, Alpine fold–thrust belt.

Abstract. During Serravallian time, a shallow–water shelf mantled by northward migrating sand waves occupied the eastern part of the Tertiary Piedmont Basin (Serravalle Sandstone, Gavi area). Towards the west, the shelf graded into a basinal zone through a series of steps probably controlled by synsedimentary faults. The autochthonous sediments of the shelf–basin transition were sandy siltstones, which are interbedded in the stratigraphical column with sands carried from near–shore areas by tectonically–triggered sediment gravity flows. On the proximal "steps", traction currents could rework these sands and re–form sand waves, while in deeper water they were buried without further reworking. Finally, at the western edge of the study area (Cassinasco), "high–density" turbidity currents flowing towards the ENE deposited the sands of the Cassinasco Fm. onto the deep bottom of the basinal zone.

Two distinct petrofacies characterize the Serravalle hybrid arenites (bioclastic lithic arkoses) and the Cassinasco sandstones (litharenites), pointing to different source terranes. The Cassinasco Fm. was fed by the Alpine fold–thrust belt, comprising Carboniferous metasediments, Permian igneous rocks, Mesozoic sediments and the Ligurid Allochthon. The paragenesis of lithic fragments and the heavy mineral assemblage show that the source rocks have undergone blueschist facies (eoalpine) and greenschist facies (mesoalpine) polyphase metamorphism. The Serravalle arenites have a similar "aphanite" rock fragment population, but detritus from granitoid bodies is prominent and the detrital modes are closer to the Tertiary clastic units of the Apennines.

Riassunto. Nella parte orientale del Bacino Terziario Ligure–Piemontese, il Serravalliano è rappresentato da successioni prevalentemente arenacee, note come Formazione di Cassinasco e Arenarie di Serravalle. Un ambiente marino di piattaforma caratterizzava l'estremità orientale della regione studiata (Gavi), con presenza di "sand waves" migranti verso nord probabilmente sotto l'azione di correnti meteorologiche. Verso ovest la piattaforma passava gradualmente a una zona bacinale attraverso una serie di "gradini" controllati da faglie sinsedimentarie. I depositi "autoctoni" della zona di transizione piattaforma–bacino erano costituiti da siltiti sabbiose, ma processi di risedimentazione innescati dalla attività tettonica vi trasportavano occasionalmente anche sabbie costiere. Sui primi gradini queste sabbie potevano venire rielaborate da correnti trattive fino a formare nuove "sand waves", mentre a profondità maggiore esse venivano deposte e sepolte senza ulteriore elaborazione. Infine, nella parte occidentale della regione

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– This work has been carried out with the financial support of the C.N.R. (Facies analysis by M. Gnaccolini; petrographic analysis by E. Garzanti, L. Caprara and L. Mutti).

studiata (Cassinasco) si estendeva una zona bacinale attraversata da correnti di torbidità ad "alta densità" dirette da WSW a ENE.

Le Arenarie di Serravalle (arcose litiche bioclastiche) e di Cassinasco (litareniti) sono caratterizzate da petrofacies distinte per quanto riguarda la frazione sia extra– che intra–bacinale. L'apporto bioclastico è molto più importante e differenziato per le prime, e testimonia una produttività biogena notevole in condizioni di mare basso; nella Fm. di Cassinasco, invece, i fossili bentonici sono assai più scarsi. Le differenze petrografiche attestano per le due unità diverse aree di provenienza del detrito. Le arenarie di Cassinasco erano alimentate dalla catena alpina, comprendente metasedimenti carboniferi, rocce ignee permiane e sedimenti mesozoici, oltre all'Alloctono Liguride. La paragenesi dei frammenti di roccia e l'insieme dei minerali pesanti mostra che le rocce sorgenti subirono due fasi metamorfiche, una di alta pressione e bassa temperatura (eoalpina) e l'altra di pressione intermedia (mesoalpina). Le Arenarie di Serravalle sono caratterizzate da una popolazione simile di frammenti di roccia a grana fine, ma il contributo di corpi granitoidi pre–alpini è molto più importante, e le mode detritiche risultano più vicine a quelle delle formazioni clastiche terziarie dell'Appennino.

Introduction.

In the eastern part of the Piedmont Tertiary Basin the Serravallian is mainly represented by arenaceous sequences, named «Formazione di Cassinasco» (Foglio 81 Ceva, Geological Map of Italy) and «Arenarie di Serravalle» (Fogli 69 Asti, 70 Alessandria and 82 Genova). Researches carried out in the region between Gavi and Cassinasco (Fig. 1) showed that the two units are very different, both petrographically and sedimentologically.

Serravalle Sandstone

The formation has been described in detail by Boni (1967) and recently by Ghibaudo (1984). We have studied the Serravalle Sandstone cropping out in the region between Gavi (thickness 350 m; Mosna & Micheletti, 1968; Boni & Casnedi, 1970) and the Bormida River.

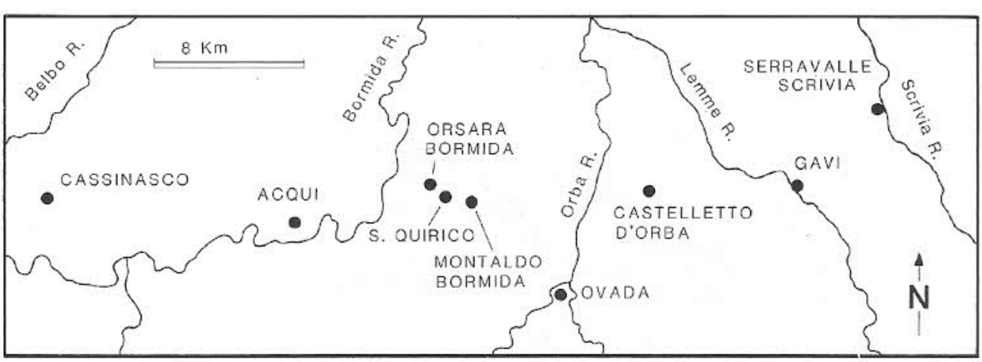


Fig. 1 – Location map of the studied area (southern Piedmont, Northern Italy).

Petrography.

A complete and well exposed, 350 m–thick sedimentary sequence was sampled along the Neirone River at Gavi, collecting samples every 15 m on the average. Care was taken to avoid weathered samples within the possibilities of hand sampling. Carbonate–leaching in outcrop is locally very extensive and most of the samples required impregnation before thin–sectioning. Many were not suitable for quantitative analysis owing to their high secondary porosity and carbonate replacements. These effects were taken into account but surely lessened the reliability of the results, caused some inconsistency among operators and consequently dimmed second–order sedimentary factors affecting sandstone composition. After preliminary textural study, 300 points were counted on selected samples (stained for calcite), according to both QFR (traditional) and QFL (Gazzi–Dickinson) methods.

The sandstones of the Gavi section are very fine to very coarse–grained, poorly to well–sorted, angular to subangular lithic arkoses (Folk, 1980; Tab. 1). As the intrabasinal carbonate fraction makes up about 50% of the framework, they are typical hybrid arenites (Zuffa, 1980).

Non–carbonate extrabasinal fraction (NCE).

Monocrystalline quartz is mostly weakly to strongly undulatory and sometimes has semicomposite extinction and abundant vacuoles («Vein quartz» of Krynine). Embayed volcanic quartz is present in traces. Among polycrystalline grains, low–grade metamorphic types (polygonized or mylonite grains) are prevalent, but «bimodal» (made up of old deformed crystals and straight newly –grown ones) and recrystallized types are common. «Oligocrystalline» grains (made of 2–3 sand–sized quartz crystals) are also present.

Among the feldspars, plagioclase and often perthitic orthoclase are common, either as single grains or in coarse–grained granitoid rock fragments. Microcline and chessboard–albite are present. Among the rock fragments granitoids prevail, but serpentineschists and felsic volcanics (commonly with quartz or even plagioclase phenocrysts in a felsitic groundmass) are frequent. Sandstones and siltstones (volcanic arenites to arkoses), orthogneisses, paragneisses, quartzites, phyllites and porphyroids, aplites, granophyres and other hypabissal clasts, chert (with or without radiolaria), greenschists, diabases and metabasites are subordinate.

Among the heavy minerals, garnet, pistacite, clinozoisite, kyanite, glaucophane and amphibole were recorded. Muscovite prevails over biotite among the micas.

Carbonate extrabasinal fraction (CE).

Sparitic and micritic limeclasts are present, while dolomitic rock fragments were never recorded.

Carbonate intrabasinal grains (CI).

Calcareous allochems are always very abundant and make up to two thirds of the framework in some cross-laminated beds. A great variety of bioclasts is present. The fauna is dominated by Bryozoans, but also Brachiopods,

N = 10		OP GSZ μ Str.			QZ	FD	RF	Acc	Intr	Int. & Aut.	Por.
AS	349	LM	X	350	28.0	9.0	21.0	1.0	18.7	17.7	4.7
AS	333	LC	=	400	12.0	7.7	22.4	0.3	22.1	25.4	10.0
AS	255	EG	X	500	12.0	4.0	15.3	0	39.3	26.0	3.3
AS	245	LC	X	750	4.0	2.7	16.0	0.3	38.3	36.0	2.7
AS	235	LM	X	650	20.3	10.0	13.0	0	42.0	11.0	3.7
AS	174	LC	X	230	32.0	6.0	19.3	1.0	10.0	26.7	5.0
AS	145	LM	=	150	14.7	4.3	4.3	0	26.7	22.0	28.0
AS	55	LC	=	220	12.3	9.7	11.0	1.7	19.3	33.0	13.0
AS	44	LM	X	100	9.3	5.7	5.3	1.3	45.7	27.7	5.0
AS	1	LM	=	375	25.7	7.7	14.7	0.3	36.0	15.0	0.7
				Mean	17.0	6.7	14.2	0.6	29.8	24.1	7.6
				Standard dev.	9.1	2.5	6.1	0.6	12.0	7.8	8.0

	S / U / C			P / F	GRA / RF
Mean	7	61	32	.50	.35
Standard dev.	5	11	12	.15	.19

Tab. 1 – Petrography of the Serravalle Sandstone; Gavi section (traditional QFR method). OP = operator (EG, LC, LM); GSZ = grain-size (median diameter); Str. = sedimentary structures (= : massive or graded sands; X : cross-stratification); QZ = detrital quartz; FD = feldspars; RF = rock fragments; Acc and Intr = accessory and intrabasinal components; Int. & Aut. = interstitial and authigenic components; Por. = large pores; S/U/C = straight/undulatory/composite quartz (in per cent); P/F = plagioclase/total feldspars ratio; GRA/RF = coarse granitoid lithics to total rock fragments ratio. Samples are numbered accordingly to stratigraphic position (distance from the base of the unit in metres).

Echinoid plates and spines, Corallinaceous Algae, Pelecypods, planktonic and benthic Forams (mainly *Amphisteginidae*), Anellids and Gastropods are common. Peloids and intraclasts are very subordinate, but large muddy intraformational clasts may have disintegrated during or shortly after deposition, as they are very commonly observed in the field. Cross–laminated sandstones, in fact, can have very high matrix content (up to 20% or even more), which is likely to be «extra–matrix» (matrix derived from obliteration of intraformational clasts; Garzanti, in press). Moderately well–sorted and coarse sands deposited by traction currents are not supposed to have such a high detrital matrix content, nor can it be accounted for by bioturbation, as lamination is well preserved, nor by vadose infiltration. If our interpretation is correct, also the negative correlation between grain– size and washing (Tab. 2) can be explained, as allochems tend to be larger than extrabasinal clasts and concentrated in coarser samples.

Non–carbonate intrabasinal grains (NCI).

Glaucony is common.

Authigenic components.

Calcite cements are abundant in some samples, while quartz and feldspar overgrowths are rare and poorly developed. Late calcite replacements at the expense of framework and interstitial carbonates but also of siliciclasts are extensive in many samples. Calcite leaching is more effective in finer–grained samples and in the middle–upper part of the section. Selective partial solution affected also serpentineschists and feldspars.

	Age	GSZ	WSH	SRT	RDN
Age		−.55	+.31	+.13	−.65
GSZ	+.28		−.77	−.61	+.64
WSH	+.36	+.30		+.66	−.60
SRT	+.52	−.41	+.36		−.60
RDN	+.09	+.70	+.10	−.23	

GAVI

CASSINASCO

Tab. 2 – Textural interrelations in the Gavi (upper right) and Cassinasco (lower left) sections. Spearman rank correlation coefficients are underlined if significant at the 5% level. Age = age of the bed; GSZ = grain–size; WSH = washing; SRT = sorting; RDN = roundness.

Facies analysis.

The following lithofacies have been identified:

AS1 – Polimictic, pebble to cobble conglomerates (a boulder up to 2 m has been observed south of Castelletto d'Orba), with variable amounts of sandy matrix. Maximum bed thickness 2 m.

AS2 – Intraformational conglomerates, with mud intraclasts up to 40 cm and coarse to medium sandy matrix. Beds from 35 to 90 cm–thick.

AS3 – Very coarse to medium hybrid arenites. They are massive or show rough graded–bedding and often contain mud intraclasts up to 15 cm or locally granules or small pebbles (the arenites can also pass laterally to sandy conglomerates). Bed thickness generally from 20 cm to 2 m, but near Orsara Bormida a 10 m–thick layer containing mud intraclasts up to 3 m has been observed.

AS4 – Graded hybrid arenites, locally with mud intraclasts, passing from medium or fine grain–size at the bottom of the layer to fine or very fine sand at the top. Bed thickness from 4 to 70 cm.

AS5 – Hybrid arenites showing a graded interval followed, at the top of the bed, by a thin interval with parallel lamination. Two cases have been distinguished: AS5a layers (thickness from 25 cm to 1.9 m) pass from coarse to very coarse grain–size at the bottom of the bed to medium and fine sand at the top and frequently contain mud intraclasts up to 70 cm; AS5b arenites (thickness from 12 to 40 cm) pass from medium or fine to fine or very fine grain–size.

AS6 – Hybrid arenites with a graded interval followed by parallel lamination and finally by a very thin interval with ripple cross–lamination. Grain–size decreases from medium at the bottom of the layer to fine at the top. Bed thickness from 8 to 40 cm.

AS7 – Fine hybrid arenites with current–ripples. Bed thickness from 2 to 4 cm.

AS8 – Fine to medium–grained, locally bioturbated, massive hybrid arenites. Bed thickness from 2 to 10 cm (exceptionally up to 40 cm).

AS9 – Coarse to fine–grained hybrid arenites with medium to large scale cross–lamination. The weakly festoon–shaped or tabular sets of invariably northward dipping cross–laminae are 20 cm to about 2 m–thick. Burrowing is locally extensive along the surfaces of single laminae. Slump features are locally present.

AS10 – Extensively bioturbated sandy siltstones (Folk, 1980, p. 26) with benthic and planktonic Foraminifera (Boni, 1967; Mosna & Micheletti, 1968). $CaCO_3$ content is 35 to 50% (determined by calcimetry). Thickness from a few cm to about 2 m.

In the **Gavi region,** the lower part of the Serravalle Sandstone (70–75 m) is characterized by a high variability of lithofacies. The AS10 prevails and rhythmically alternates with all the lithofacies from AS2 to AS9 (Fig. 2A). The main body of the unit, instead, is mostly represented by lithofacies AS9 (Fig. 2, middle and upper part of section C), with some intercalations of AS3 and AS1. In one locality, the AS9 arenites show a well-developed hummocky cross-stratification.

Main body of the Serravalle Sandstone. The lithofacies AS9 is inferred to testify ancient «sand waves» (a similar interpretation is given by Ghibaudo, 1984, for the Serravalle Sandstone in the type-locality). Sand waves have been frequently described in the sublittoral environment, and their origin has been ascribed to: a) meteorological currents (winds, waves, storms); b) tidal currents; c) oceanic currents intruding onto the shelf; d) internal wave-generated cur-

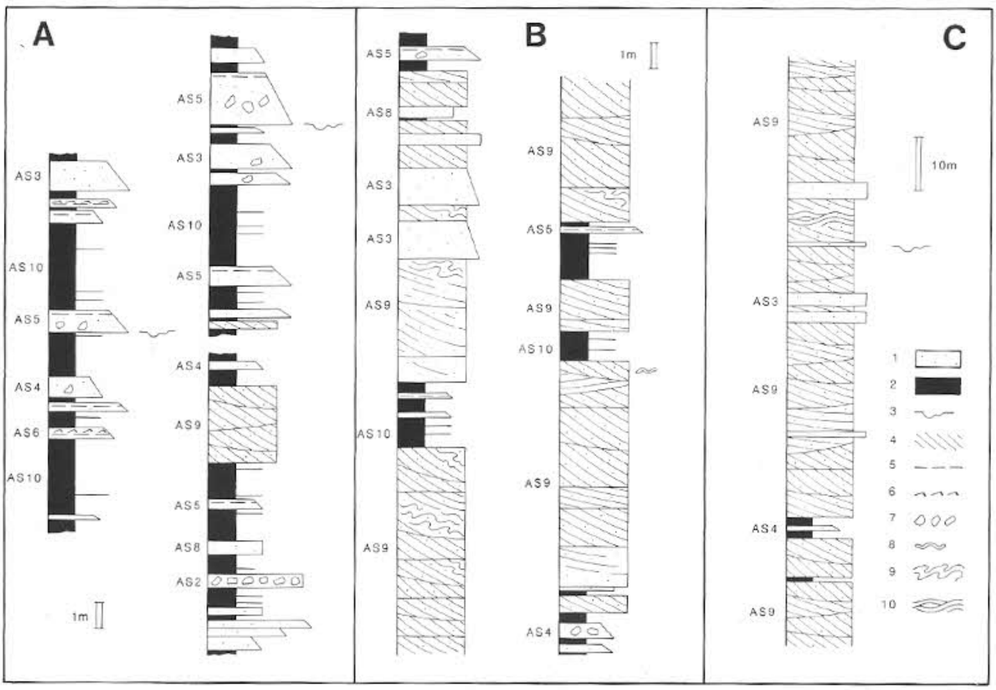


Fig. 2 – Serravalle Sandstone, Gavi section: examples of lithofacies associations in the lower part (A, B) and in the main body of the formation. 1) Sandstones; 2) siltstones; 3) scour-and-fill; 4) cross-bedding; 5) parallel lamination; 6) ripple cross-lamination; 7) mud intraclasts; 8) burrows; 9) slumpings; 10) hummocky cross-stratification. See text for explanation of the lithofacies code.

rents (Swift, 1976; Swift & Ludwick, 1976; Flemming, 1978; Johnson, 1978; Walker, 1979; Bouma et al., 1982; Karl & Carlson, 1982; Blakey, 1984). The occurrence of hummocky cross–stratification indicates reworking by storm–generated currents and suggests a water–depth between fair weather wave–base and storm wave–base (from a few metres to several tens of metres; Walker, 1979; Dott & Bourgeois, 1982).

Lithofacies AS3 and AS1, locally interbedded with lithofacies AS9, are thought to represent mass deposits, probably generated by submarine slides in near–shore areas (see below for discussion).

Lower part of the Serravalle Sandstone. While lithofacies AS10 is interpreted as an autochthonous sediment deposited off–shore relative to the sand wave area, lithofacies AS2, AS3 and AS5a seem to represent sediment gravity flow deposits, mainly connected with the tectonic instability of the area. This interpretation is supported by:

a) the very large size of the mud intraclasts (up to 40 cm in AS2 deposits; exceptionally up to 3 m in AS3 and up to 70 cm in AS5a lithofacies);

b) the thickness of the sedimentation units (up to 2 m and exceptionally up to 10 m for AS3; up to 1.9 m for AS5a);

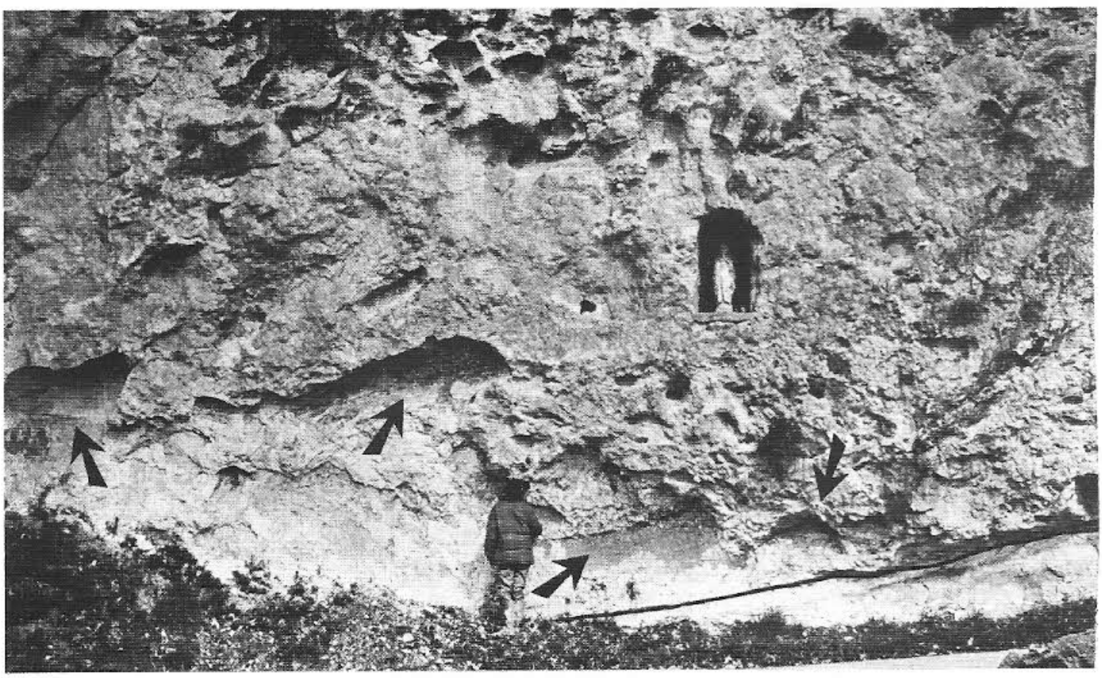


Fig. 3 – The 10 m–thick AS3 megabed near Orsara Bormi

c) the occurrence of small synsedimentary faults (Gavi fort) and of slump features in the associated AS9 sediments.

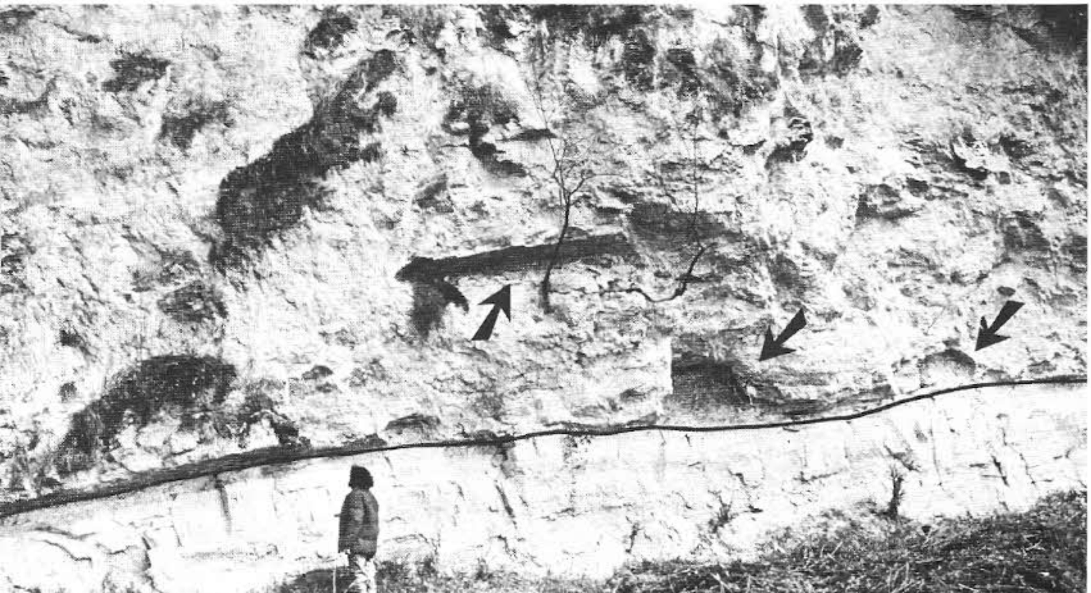
The other lithofacies (AS4, AS5b, AS6, AS7 and AS8) were considered as storm–controlled deposits in the type–locality of the unit (Ghibaudo, 1984). Owing to the close relationships with the lithofacies AS2, AS3 and AS5a, however, they may partly represent the distal facies of tectonically–triggered sediment gravity flows.

The alternation of several lithofacies at the base of the formation can be explained as follows:

a) the sedimentary environment was farther from the coast (circalittoral to deeper, lithofacies AS10);

b) from time to time, tectonic activity caused slumping of proximal deposits, thus generating sediment gravity flows (lithofacies AS2 to AS8). Sand waves were formed again (lithofacies AS9) when these sediments were reworked by tractive currents.

To the **west of Gavi** the Serravalle Sandstone shows relevant differences relative to the Gavi section. Lithofacies AS3 becomes more and more important, whilst lithofacies AS9 becomes gradually less widespread. Near Castelletto



ntaining mud intraclasts up to 3 m in size (arrows).

d'Orba, AS3 deposits, with some intercalated AS1, form the whole lower part of the unit. Lithofacies AS9 still prevails in the upper part. More westward, AS9 arenites were observed at Roccagrimalda (just North of Ovada) and near Montaldo Bormida, while near S. Quirico and Orsara Bormida the Serravalle Sandstone consists almost exclusively of sediment gravity flow deposits. Near Orsara, the unit begins with a 10 m–thick layer of lithofacies AS3 containing mud intraclasts up to 3 m (Fig. 3). Therefore, we think that closer to the Bormida River the Serravalle Sandstone was deposited in a deeper–water sedimentary environment: from the Gavi shelf a probably block–faulted sea bottom deepened westward, where the Cassinasco basin was established.

Cassinasco Formation

The Cassinasco Fm. cropping out in the type–locality was studied in detail. In this area the unit is about 600 m–thick.

Petrography.

Along the road from Bubbio to Cassinasco, the lower 400 m of the unit were sampled every 15 m on the average. The sandstones of the Cassinasco section are very fine to coarse–grained, poorly to moderately sorted, angular litharenites (Tab. 3), with average composition $Q_{31} F_6 L_{62}$ ($Q_{27} F_5 L_{67}$ including extrabasinal carbonate detritus). Paleocurrent measures in the type–section have yielded a vector mean of 75°N (magnitude of the resultant vector = 81%). The 42 measures have unimodal distribution and are scattered between 0° and 170° N (standard deviation = 37°).

Non–carbonate extrabasinal fraction (NCE).

Monocrystalline quartz is mostly undulose and sometimes has semicomposite extinction. Attached felsitic groundmass can often be observed, attesting provenance from felsic volcanic rocks. Unstable and stable (Young, 1976) polycrystalline grains are present in subequal amounts. Feldspars are rare and plagioclase (mostly albite, sometimes with chessboard twinning, common also in low –grade meta–igneous lithics) generally prevails over K–spar.

Coarse–grained granitoid rock fragments are not abundant and commonly show metamorphic textures. Also felsitic volcanic rock fragments have mostly foliated fabric and probably derived from meta–rhyodacites, as phenocrysts are invariably deformed quartz or even untwinned albite. Hypabissal grains, quartz with inclusions of vermicular chlorite and granophyres are present in traces. Among metasedimentary lithic types, quartzites, paragneisses (sometimes with albite or microcline), micaschists, carbonaceous phyllites and slates are all very common. Serpentineschists, chloritoschists, blueschists, diabases and albite «stuffed» with epidotes or even garnet, chlorite and sphene also occur. Chert with selectively dissolved dolomite rhombs and terrigenous sedimentary rock fragments are less frequent.

The heavy mineral fraction is very rich and includes glaucophane (present in all samples), pistacite, clinozoisite, zoisite, chloritoid, garnet, sphene, kyanite, staurolite, clino– and orthopyroxene, amphibole, tourmaline, rutile and zircon. Muscovite largely prevails over biotite and chlorite.

N = 13		OP	GSZ μ	Paleoc.	QZ	FD	RF	Acc	Intr	Int. & Aut.	Por.
FC	380	LC	120	120	11.3	1.7	41.7	3.7	5.3	34.7	1.7
FC	340	LC	70	325	13.0	1.7	45.0	1.0	0.7	37.7	1.0
FC	312	LC	50	200	20.3	1.0	40.7	0.7	2.7	34.0	0.7
FC	234	LM	130	300	19.0	1.4	45.9	3.8	10.3	16.2	3.4
FC	201	LM	90	140	19.7	2.7	49.7	7.3	3.3	16.7	0.7
FC	175	LC	?	160	19.0	2.7	43.0	2.3	4.3	27.3	1.3
FC	144	LM	120	180	18.4	2.8	39.2	3.6	15.2	20.4	0.4
FC	130	LC	50	170	15.0	5.0	44.7	2.3	3.0	27.7	2.3
FC	83	LM	60	450	19.1	2.0	43.1	0.8	10.6	24.4	0
FC	75	EG	170	800	9.3	1.3	64.9	4.6	1.3	11.9	6.6
FC	56	LC	110	250	14.3	1.7	52.3	3.7	3.3	23.3	1.3
FC	37	LM	70	130	16.3	6.3	43.3	4.0	11.3	17.7	1.0
FC	1	EG	100	275	9.9	4.6	57.6	1.3	0	26.5	0
				Mean	15.7	2.7	47.0	3.0	5.5	24.5	1.6
				Standard dev.	3.9	1.6	7.4	1.9	4.8	7.9	1.8
					S / U / C			P / F		GRA / RF	
				Mean	12 50 38			.57		.04	
				Standard dev.	7 8 9			.16		.03	

Tab. 3 –Petrography of the Cassinasco Formation; Cassinasco section (traditional QFR method). Paleoc. = paleocurrent direction; other symbols as in Tab. 1.

Carbonate extrabasinal fraction (CE).

Dolomitic and micritic rock fragments (often with pre–depositional fractures or foliated fabric) are present. Lithics made of sparry calcite are also present, but often difficult to tell from authigenic calcite. Calcschists can be very abundant (up to 15% of the framework in the coarsest sample).

Intrabasinal fraction (CI and NCI).

Allochems are much less abundant than in the Gavi section, but benthic and planktonic Forams, Brachiopods, Echinoderms, Bryozoans, Pelecypods, Algae and Radiolaria are present. Glaucony and phosphatic (fish) bone fragments are rare.

Interstitial and secondary components.

Some silty and clayey orthomatrix occurs, but it is impossible to assess the original amounts of «matrix», due to late calcite replacements. Extramatrix is also present and abundant in some samples. Cements (mostly calcite, with rare tectosilicate overgrowths) can exceed 10% . Solution and replacements selectively affected feldspars, serpentineschists and particularly dolomitic rock fragments. Micas are almost undeformed, and unstable heavy minerals escaped intrastratal solution, showing that the Serravallian sediments were never buried deep during post–depositional history.

Facies analysis.

The observed lithofacies are the following:

FCI – Intraformational conglomerates with mud intraclasts up to 25 cm and sandy matrix (one layer, 70 cm–thick).

FC2 – Graded litharenites. Two types have been identified: FC2a beds (30 cm to 3.8 m–thick) are mostly coarse–grained at the bottom and fine–grained at the top and often contain mud intraclasts up to 1 m. FC2b beds (8 cm to 1.4 m–thick) pass from fine or medium grain–size at the bottom to very fine grain–size at the top. They locally contain mud intraclasts up to 1.5 m.

FC3 – Litharenites with a graded interval followed by parallel lamination. Grain–size passes from medium or fine to very fine. Locally mud intraclasts (up to 70 cm) are present. Bed thickness from 12 cm to more than 1 m.

FC4 – Thin–bedded (3 to 10 cm), parallel–laminated fine–grained litharenites.

FC5 – Thin–bedded (6 to 13 cm), fine–grained sandstones with current–ripples.

FC6 – Siltstones with planktonic Foraminifera (Gelati, 1968). Carbonates are 25 to 55%. Thickness from a few cm to 2 m.

Lithofacies FC2 is by far the most characteristic, and rhythmically alternates with lithofacies FC6 (Fig. 4). The sandstone beds have very sharp base, while the transition with the overlying siltstones is always very gradual. In the FC2 + FC6 couple, the sandstone is largely prevalent in the lower part of the Cassinasco Fm., where the pelitic intervals are generally only a few cm–thick. Only in the middle and upper part of the formation the mud/sand ratio locally approaches or even exceeds unity. Slump features are locally present. All other lithofacies are very minor.

The Cassinasco Fm. has long been interpreted as deposited by turbidity currents running from WSW to ENE (Gnaccolini, 1968). In particular, the observed lithofacies can be ascribed to «high–density» turbidity currents flowing in a basin extended from the Ceva area to Acqui (Gelati & Gnaccolini, 1982).

Paleogeographic setting

During Serravallian time the most eastern part of the Tertiary Piedmont Basin was covered by a shallow–water sea. Its bottom was mantled by sand waves, probably generated by meteorological currents (Serravalle Sandstone,

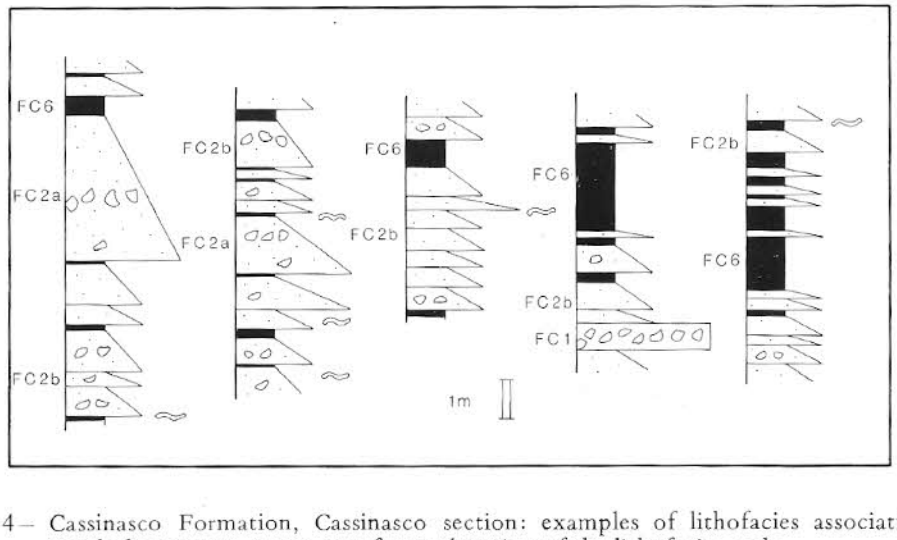


Fig. 4 – Cassinasco Formation, Cassinasco section: examples of lithofacies associations. Symbols as in Fig. 2. See text for explanation of the lithofacies code.

middle and upper part of the Gavi section). This area (number 1, Fig. 5) graded into a basinal zone through a sequence of «steps», probably controlled by NNE–SSW synsedimentary faults. The sea–bottom became progressively deeper westward, towards the basin. The autochthonous sediment of this fault–controlled shelf–basin transition was a sandy siltstone, but tectonically–triggered sediment gravity flows were sometimes able to carry near–shore sands onto the deeper–water «steps». On the more proximal steps (number 2, Fig. 5), bottom currents could rework these sands, re–forming sand waves which alternate with siltstones in the stratigraphical record (Serravalle Sandstone; lower part of the Gavi section). On the deeper «steps» (number 3, Fig. 5) traction currents were ineffective, and the resedimented sands were mostly buried without further reworking (Serravalle Sandstone; S. Quirico, Orsara Bormida).

Westward, «high–density» turbidity currents deposited the sands of the Cassinasco Fm. onto the deep bottom of the basinal zone (number 4, Fig. 5).

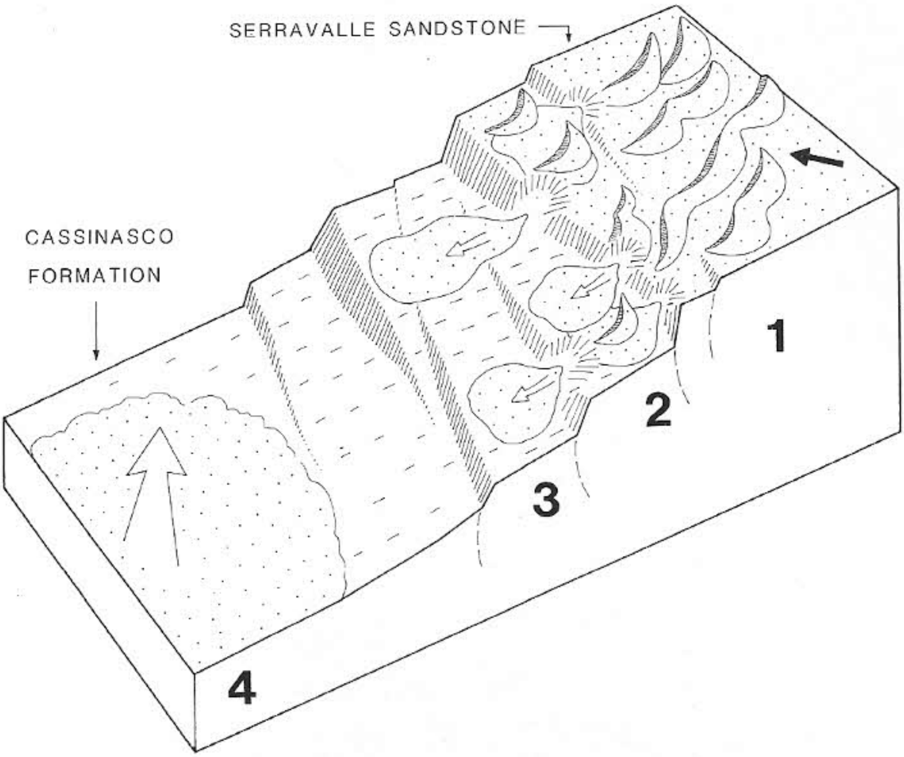


Fig. 5 – Paleogeographic setting of the area between Gavi and the Bormida River during Serravallian time (not to scale). Black arrow indicates the direction of migrating sand waves (towards the present geographic North); white arrows show the movement of sediment gravity flows. See text for further explanation.

A similar transition has been inferred by Casnedi (1983) to the North of Gavi and Serravalle from subsurface data (wells and seismic lines).

Provenance of the sand

The general purpose of this preliminary petrographic study of the sandstones contained in the Serravallian type–area is to provide some information about the source rocks eroded to feed the depositional systems. We also wanted to test if any major difference in composition existed between the Serravalle Sandstone and the Cassinasco Fm., between lithofacies (massive or graded versus cross–bedded sands) and among layers with different paleocurrent directions. In addition, the compositional trends within each stratigraphic section were analysed and tested for significance.

The Serravalle hybrid arenites and the Cassinasco sandstones represent in fact two distinct petrofacies (Fig. 6). Their mineralogy reflects different source areas, as textural control, operator inconsistencies, diagenetic and stratigraphic effects are all subordinate. Sedimentary factors can only explain minor petrographic differences within the Gavi section (coarse cross–laminated sandstones are better rounded and also tend to be feldspar–poor and rich in allochems). Rounding of framework grains (serpentineschists in particular, with ρ up to 6) and possibly selective destruction of mechanically labile metasedimentary rock fragments (Cameron & Blatt, 1971) can be ascribed to reworking on the Gavi shelf. Composition does not vary systematically with paleocurrent direction in the Cassinasco section (Fig. 6, top left), but feldspars decrease in younger sandstones. No other significant dependence on stratigraphic position was detected (Tab. 4).

The Serravalle Sandstone is much more feldspathic, while the Cassinasco Fm. is quartzolithic. Granitoid rock fragments are abundant in the Serravalle Sandstone, while the Cassinasco Fm. is very rich in all types of metamorphic lithics. But, in spite of marked differences in feldspars and feldspar–bearing coarse–grained plutonic clasts, the aphanitic rock fragment population is similar (distinguishable only in second–order diagrams, Fig. 6), pointing to provenance from a common orogenic belt. The composition of the Serravallian sandstones indicates in fact a composite Collision Orogen source (Dickinson & Suczek, 1979), with major contribution from a volcanoplutonic terrane more dissected towards the east (Gavi area). The tectonite fabric of igneous rock fragments and albitization and deformation of the crystals rule out the possibility of major penecontemporaneous magmatic activity (igneous detritus is «palaeo», sensu Zuffa, in press).

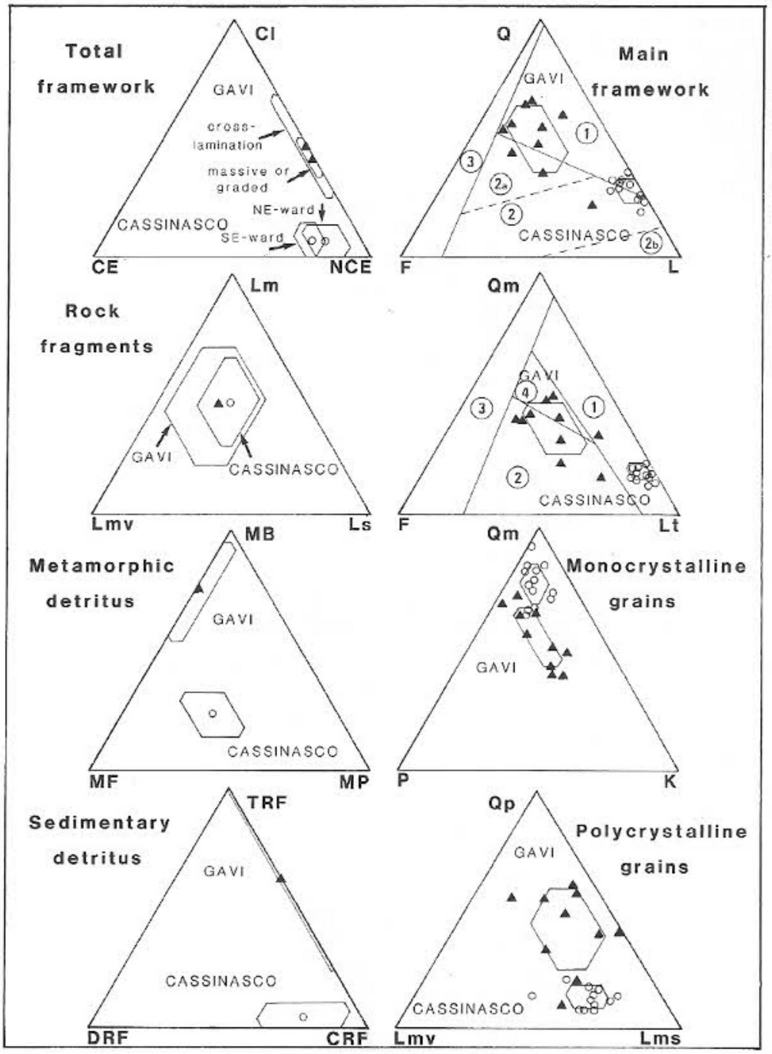


Fig. 6 – Petrography of the Serravallian sandstones (Gazzi–Dickinson QFL method); Gavi (black triangles) and Cassinasco (circles) sections. Polygons are one standard deviation each side of the mean. NCE, CE and CI = non–carbonate extrabasinal, carbonate extrabasinal and carbonate intrabasinal components (Zuffa, 1980). Q = total quartz (Qm = monocrystalline; Qp = polycrystalline, including little chert); F = total feldspars (P = plagioclase; K = K–spar + chessboard–albite); L = fine–grained rock fragments (Lmv = volcanic and metavolcanic; Lms = sedimentary and metasedimentary, including CE detritus); Lt = L + Qp = total lithics; Lm = metamorphic lithics (MB = metabasites: greenschists and serpentineschists; MF = metafelsites: quartzites and gneisses; MP = metapelites: slates and schists); Ls = sedimentary lithics (TRF, DRF and CRF = terrigenous, dolomitic and calcareous rock fragments). Numbers in the QFL and QmFLt diagrams refer to the provenance fields of Dickinson et al. (1983): 1) Recycled orogen; 2) Magmatic arc (2a = Dissected; 2b = Undissected); 3) Continental block; 4) Mixed.

The Cassinasco source rocks have undergone stronger deformation, with blueschist facies (eoalpine) and greenschist facies (mesoalpine) polyphase metamorphism, as shown by the paragenesis of rock fragments and by the heavy mineral assemblage. The sandstones were thus derived from the alpine fold–thrust belt (Fig. 7) made of stacked nappes of low to medium–grade mainly Carboniferous metasediments (paragneisses, phyllites, micaschists), Permian igneous and sedimentary rocks (orthogneisses, quartzose porphyroids and meta–arenites type Verrucano), mainly Triassic shelf sediments (dolostones and limestones) and Jurassic to Cretaceous oceanic rocks (ophiolites, cherts and calcschists). As a source terrane, the Penninic nappes of the Marittime Alps could well account for the composition and the paleocurrents of the Cassinasco Fm.

The source area of the Serravalle Sandstone was much richer in granitoids, associated with slightly or non–metamorphic rhyodacites and volcanic arenites. Also older metasediments and the Ligurid subduction complex with serpentineschists and radiolarites were eroded. Sedimentary detritus was subordinate. The detrital modes can be closely compared with those of Tertiary Apenninic sandstones with recycled orogenic to composite provenance (Gazzi & Zuffa,

Dependence on Stratigraphy	Main Framework			Monocrystal. Grains			Polycrystal. Grains		
	Q	F	L	Qm	P	K	Qp	Lmv	Lms
GAVI	+.33	+.10	–.30	+.28	–.49	–.09	+.07	–.25	+.13
CASSINASCO	–.33	+.63	–.00	–.74	+.63	+.54	–.23	+.17	+.01
	Quartz			Feldspars			Rock Fragments		
	S	U	C	F/Q	F/Lt	P/F	Lmv/Lt	MS/NCE	MB/NCE
GAVI	+.15	+.42	–.46	–.02	+.12	–.04	–.10	+.07	+.05
CASSINASCO	+.22	–.37	+.15	+.72	+.62	–.23	+.20	+.02	+.35

Dependence on Grain–size	Quartz			Feldspars			Rock Fragments		
	S	U	C	F/Q	F/Lt	P/F	Lmv/Lt	MS/NCE	MB/NCE
GAVI	–.03	–.10	+.11	+.15	+.10	–.28	–.08	–.37	–.44
CASSINASCO	–.17	–.32	+.42	+.06	+.63	–.00	+.03	+.52	+.54

Tab. 4 – Correlations between composition, age of the bed (Stratigr.) and grain–size. MS = metasedimentary lithics (MP + MF); other symbols as in Tab. 1 and Fig. 6. Pearson's correlation coefficients are underlined if significant at the 5% level. Consider that dependence on grain–size is minimized by the QFL method.

1970; Valloni, 1978; Deneke & Günther, 1981; Gandolfi et al., 1983). In particular, Mezzadri & Valloni (1981) estimated for the Early Miocene Cervarola Sandstone an average composition of $Q_{52}F_{30}$ L_{18}, with plagioclase to total feldspars ratio of .48, which matches that of the Serravalle Sandstone ($Q_{51}F_{28}$ L_{22}, or $Q_{49}F_{27}L_{24}$ including carbonate rock fragments, very similar P/F ratio and lithic types). The problem of locating their granitoid–bearing source terrane in internal or external alpine units is a crucial one for understanding the relations between the Alpine and the Apenninic orogens.

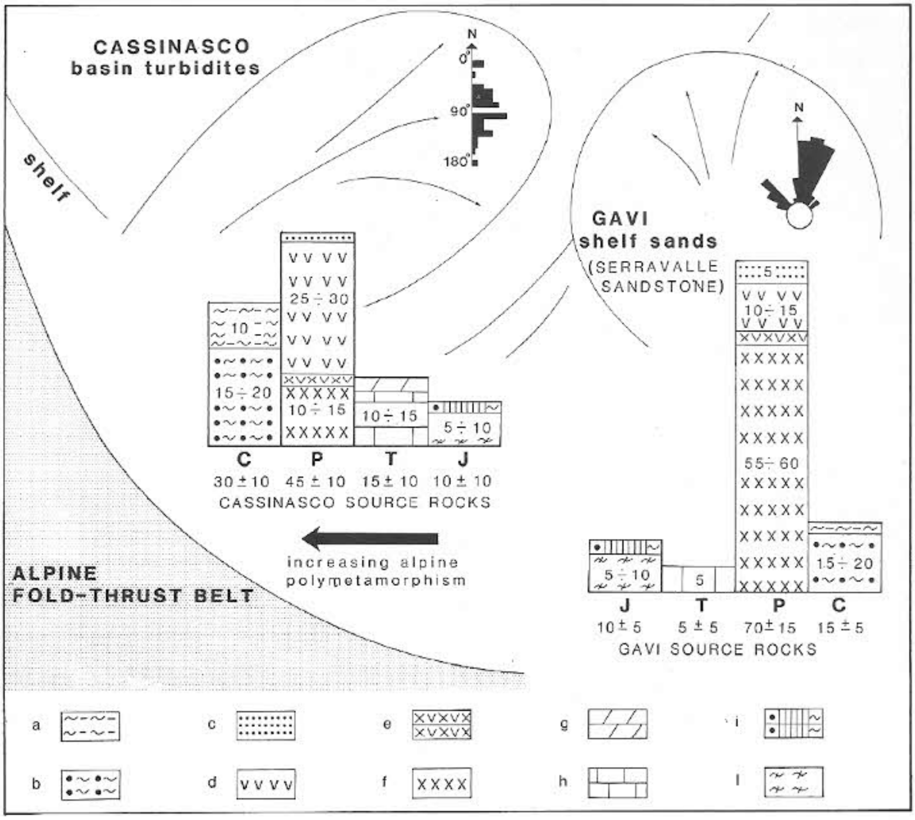


Fig. 7 — Provenance and dispersal patterns for the Serravallian sandstones. Tentative estimates of the proportions of the source rocks eroded to produce the sediments are given for the Gavi and Cassinasco sections. Calculations do not consider the effects of weathering and transport. «Unlabelled» single minerals were genetically apportioned proportionally to their occurrence in coarse–grained rock fragments. C = «Carboniferous» metasediments (a = schists; b = gneisses); P = «Permian» igneous rocks and cover (c = sandstones; d = rhyodacites; e = hypabissal bodies; f = granitoids); T = «Triassic» carbonates (g = dolostones; h = limestones); J = «Jurassic» oceanic rocks (i = cherts and calcschists; l = ophiolites)' Paleocurrent data for the Serravalle Sandstone after Ghibaudo (1984). Metamorphism of source rocks increases westward.

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