PROVENANCE FROM OPHIOLITES AND OCEANIC ALLOCHTONS: MODERN BEACH AND RIVER SANDS FROM LIGURIA AND THE NORTHERN APENNINES (ITALY)

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ABSTRACT

The Northern Apennine arc consists of allochtonous oceanic units (Ligurids) and synorogenic terrigenous wedges, and includes both alpine (Voltri Massif) and apenninic (Bracco Unit) ophiolitic complexes and isolated slabs of oceanic lithosphere (Casanova Complex). Detritus transported by streams in this vast region, comprised between Bologna and Alessandria, and sand of Liguria beaches from Savona to La Spezia can be distinguished - through analysis of framework composition and transparent heavy mineral suites - in four provinces, further subdivided in sub-provinces and variants.

The Apennine Province and the Antola Province are carbonaticlastic and characterized by recycling of Ligurid flysches, whereas the Voltri Province and the Bracco Province are dominated by ophioliticlastic detritus. Along the boundaries of major ophiolitic complexes various sub-provinces with mixed provenances characerized by significant ophioliticlastic detritus are recognized (Bormida di Spigno and Polcevera river sands, and Celle-Varazze beach sands for the Voltri Massif; Vara, Lavagna and Ghiaiaro river sands for the Bracco Unit). Ophiolite-derived material dominates the heavy mineral fraction also in the sand transported by major streams draining the Emilia Apennines (Trebbia, Nure, Taro).

Framework composition and heavy mineral suites clearly differentiate the serpentineschist- and amphibole-rich (glaucophane, actinolite) detritus derived from alpine ophiolites involved in thick-skinned deformation and high-pressure metamorphism (Voltri Massif), from the serpentinite- and pyroxene-rich (diallage) detritus derived from oceanic lithosphere involved in thin-skinned deformation within the Apennine belt (Bracco Unit; Casanova Complex). In the study of ancient perisutural-basin clastic wedges, these criteria can help reconstructing subduction style and paleogeodynamic evolution of associated suture belts.

INTRODUCTION

The Northern Apennines - up to the boundary with the Liguria Alps - consist of a stack of thrust-sheets derived from the Ligurian-Piedmont oceanic domain, first deformed during shallow E-ward alpine subduction in the Paleogene and subsequently carried eastward during steep W-ward subduction of Adria since the Oligocene. The evolution of the Alps/Apennines orogenic couple has determined the complex geologic structure of northwestern Italy and - as a direct consequence - the nature of detritus transported by modern tributaries of the Po River on one side and deposited along the Liguria coast on the other side.

The principal aims of the present work are: 1) to recognize and describe the main provinces - as regards both framework petrography and transparent heavy mineral suites - of fluvial and beach sand on the opposite sides of the Apennine orogen; 2) to relate modern provenance with the geologic evolution of the Alpine and Apenninic mountain belts; 3) to provide an actualistic analogue for provenance studies of ancient ophiolite-derived sands.

METHODOLOGY

Study area, sampling, analytical procedures

This study focuses on the vast region of the Northern Apennines and Liguria Alps where ophiolitic sequences are exposed (over 15.000 km^2; Fig. 1). Sampling was carried out in central and eastern Liguria, between Savona and La Spezia (19 rivers and 20 beaches) and on the southern margin of the Po Plain from Alessandria to Bologna (24 rivers). Fluvial sand was collected from point bars or longitudinal bars preferentially at low discharge; Liguria rivers were sampled a few hundred metres from the mouth, whereas Apennine rivers were mostly sampled within a few km from the mountain front. Beach sand was collected preferentially from the berm, but in gravelly beaches sand had to be collected where available (either in the backshore or in the foreshore).

300 points were counted on the 63 collected samples according to the Gazzi-Dickinson point-counting method. A classification scheme including 12 classes and over 80 categories of grain-types has been devised with the aim of recording full quantitative information on coarse-grained rock fragments; also traditional Q-F-R parameters can thus be easily recalculated from the obtained data set, thus meeting all possible needs (e.g., Ingersoll et al., 1984; Decker and Helmold, 1985; Suttner and Basu, 1985; Zuffa, 1985). Main accessory, intrabasinal, anthropic and "unknown" components were also distinguished. Median grain size of counted samples - determined both with standard sieving techniques and by ranking and visual comparison - ranges between 140 and 1000 microns.

For 33 selected samples, 200 transparent heavy minerals were counted on grain mounts, according to the "ribbon-counting" or "Flett" methods (Mange and Maurer, 1992). Heavy minerals were concentrated with high-density liquids (bromoform or sodium metatungstate), using only the 63 to 250 micron size fraction treated with hydrogen peroxide, oxalic and acetic acid to eliminate organic matter, iron oxides and carbonates respectively (Parfenoff et al., 1970). In order to dissolve carbonates, samples from tributaries of the Po River and carbonate-rich Liguria samples have been treated with chloridric acid, whose more rapid and effective action on the other hand eliminates minerals such as phosphates and olivine.

The sampling plan was devised with the purpose of representing with sufficient detail the various geological complexities of the area as a whole. Definition of petrological characteristics of single drainage basins - or of segments of

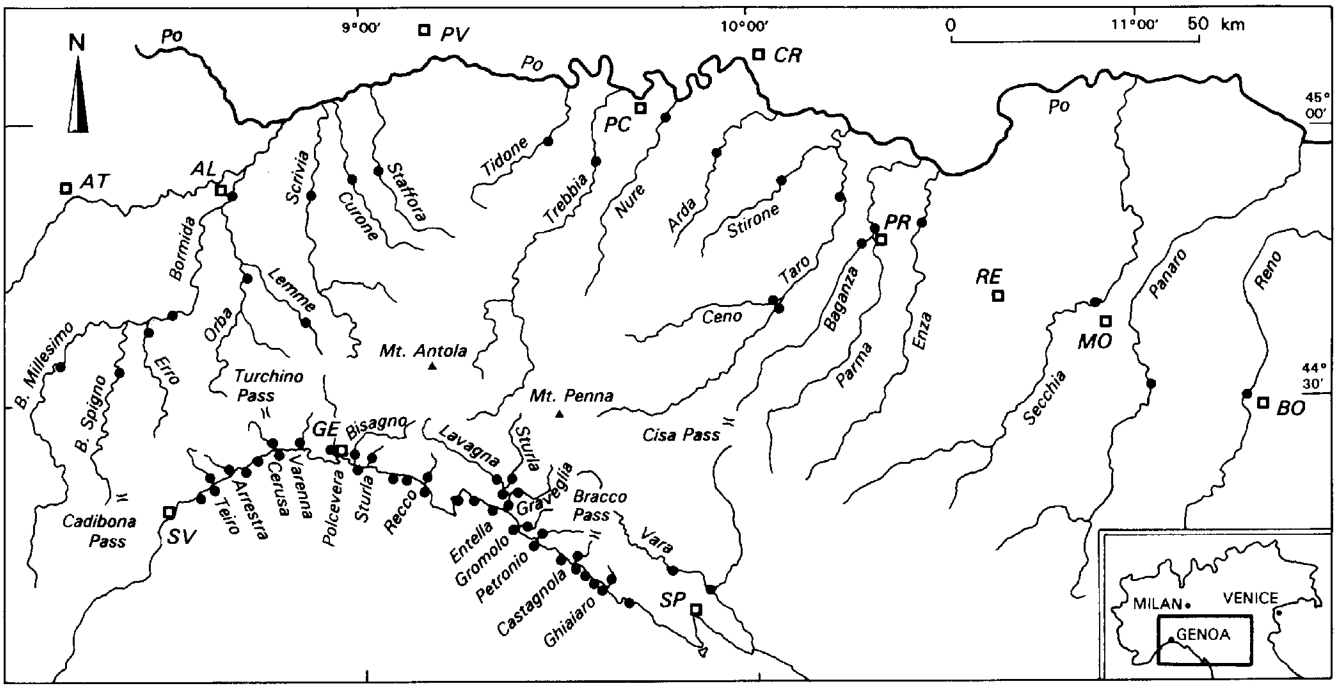

Fig. 1 - Simplified geographic map of Liguria and the Northern Apennines. Studied rivers and location of 63 analyzed samples (black dots) are indicated. AL= Alessandria; AT= Asti; BO= Bologna; CR= Cremona; GE= Genova; MO= Modena; PC= Piacenza; PR= Parma; PV= Pavia; RE= Reggio Emilia; SP= La Spezia; SV= Savona.

longshore transport - will obviously require work at a different, larger scale (e.g., Ingersoll, 1990).

Parameters, plots, terminology

Longshore transport by marine currents favours mixing and homogenization of detritus (e.g., Ingersoll et al., 1993), thus allowing recognition of geographic areas in which beaches have comparable composition ("provinces"; e.g., Le Pera and Critelli, 1997). Petrographic provinces can be recognized also for detritus transported by subparallel to radial streams draining geologically homogeneous source areas. Some rivers - typically including major ones - run instead along main geologic boundaries, and are commonly characterized by peculiar mixed compositions.

Provinces and subprovinces by no means can be effectively discriminated with traditional QFL-type parameters (QtFL, QmFLt, QmPK, QpLvmLsm, LmLvLs of Dickinson, 1970; 1985; Ingersoll, 1983), plotted three by three on canonical triangular diagrams. In order to obtain a simple but complete synthesis of framework composition, a wider spectrum of eight compositional key indexes have been devised and used: Q= quartz; F= feldspars; Lv= volcanic lithics; Lc= carbonate lithics; Lt= terrigenous lithics; Lch= chert; Lm= metamorphic lithics; Lo= serpentinite and serpentineschist lithics. Key indexes also allow to define - in addition to the usual generic and purely descriptive names (e.g., litharenite; quartzo-lithic sand) - also specific and more informative terms with provenance implications (e.g., volcaniclastic, carbonaticlastic, metamorphiclastic, ophioliticlastic sand; Ingersoll, 1983; Critelli and Le Pera, in press).

Further informations on source rocks - which however have to be considered as just semiquantitative when a small number of grains is taken into account - are provided by internal ratios for each key index. In the present paper, beside the classic plagioclase/total feldspars ratio (P/F of Dickinson, 1970) - which is seldom significant due to overall scarcity of feldspar grains - the Qp/Q (Qp= polycrystalline quartz), Lvm/Lv (Lvm= microlitic to lathwork volcanic grains), Lcd/Lc (Lcd= dolostone grains), Lmb/Lm (Lmb= metabasite grains, including greenschist - chloritoschist, epidosite, prasinite - to blueschist) and Loc/Lo (Loc= massive serpentinite grains with cellular structure, including serpentinized peridotite) are considered. But for the P/F ratio, which is calculated according to the Gazzi-Dickinson method, all other ratios are calculated according to the traditional QFR method.

For a synthetic description of transparent heavy mineral suites, a spectrum of ten key indexes have been used: ZTR = ultrastable minerals (zircon, tourmaline, rutile; Hubert, 1962); T&O= titanium minerals and others (e.g., sphene, anatase, brookite, apatite, barite); Hb= hornblende; AA= other amphiboles; CPX= clinopyroxenes; OPX= orthopyroxenes; OS= olivine and spinel; LgM= low-grade metamorphic minerals (e.g., pistacite, clinozoisite, zoisite epidotes, chloritoid, pumpellyite); Gt= garnet; HgM= high-grade metamorphic minerals (e.g., staurolite, andalusite, kyanite, sillimanite).

Anthropic effects

Several Liguria beaches are severely affected by erosional processes and are periodically re-nourished both for their high touristic value and coastal protection. Sediment is commonly obtained from nearby sources (e.g., adjacent alluvial deposits), thus reducing compositional modifications, but in some cases foreign material is also used. Moreover, in highly populated areas, fragments from a variety of artificial materials (e.g., bricks, pottery, tiles, flagstones, glass, reinforced plastics, concrete, asphalt, clinker, metals) are mixed with natural sand. All possible care was taken to minimize

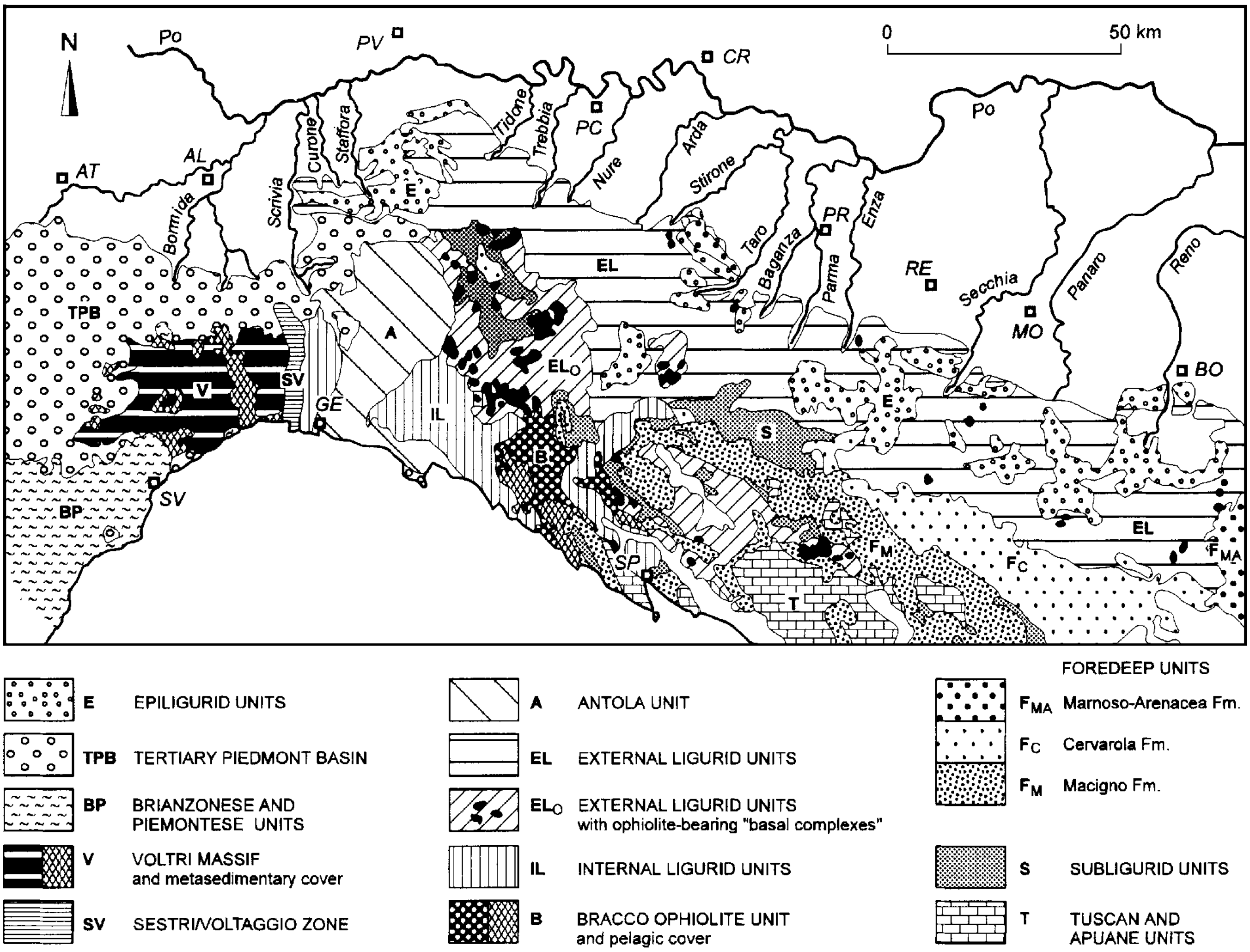

Fig. 2 - Geologic sketch map (after Consiglio Nazionale delle Ricerche, 1975, 1990, and various sources cited in text) showing areal distribution of oceanic Ligurid Units and main ophiolite complexes.

anthropic effects (e.g., collecting information from local people; taking samples from both rivers and beaches, as far as possible from dumps and bathing establishments; preparing thin sections of various artificial materials in order to make recognition easier). However, modifications of natural equilibria due to human activities are so vast and multiform (e.g., deforestation, urbanization, dams, sandpits) that, if we need data on modern environments to provide actualistic models for provenance interpretation of ancient clastic suites, we are left with little alternative than considering man as a creature with extraordinary bioturbation capabilities.

GEOLOGICAL SETTING

Topography, climate, drainage

From the elevated Reggio-Parma watershed where the Macigno is exposed, to the transversal segment dominated by Mt. Gottero, to the Mt. Penna ophiolitic peak, the Apennine divide closely follows the boundary between the compressive apenninic and extensional tyrrhenian structures (Mazzanti and Trevisan, 1978). Contrasts in topography, climate and drainage between its opposite sides are sharp.

On the steep southeastern Liguria side, slopes commonly exceed 20%, favouring rapid headward erosion and stream captures. Drainage consists of short torrential streams flowing perpendicular to the coast. Only the Entella and Vara Rivers are 40 to 50 km-long and have basins 375 to 300 km^2 wide; mean and maximum annual discharge are 15 to 20 m^3/s and 250 m^3/s, with peaks above 450 m^3/s (Entella) and 600 m^3/s (Vara). Maximum annual turbid discharge for the Entella River varies between 100 and 800 kg/s.

Along the high and rocky coast, pocket beaches largely form in correspondence of stream mouths and are at most several hundred meters-long and a few tens of meters-wide.The continental shelf is less than 10 km-wide (Fanucci et al., 1974) and longhsore transport is presumably limited, sediments being funnelled through canyons (e.g., Polcevera and Bisagno canyons) and re-deposited at bathyal depths on the Liguria Sea floor.

Due to mitigating effect of the sea in winter, climate is temperate-warm along the coast (mean annual temperature close to 15°; annual excursion about 14°C), with rainy autumns and dry summers. Due to orientation of relief with respect to humid mid-Atlantic air masses, precipitations progressively increase from the western Riviera (San Remo: 750 mm) to the eastern Riviera (Chiavari: 1150 mm). On the apenninic ridge, running less than 10 km from the sea, between 1500 and 2000 mm of rain fall in 100 to 120 rainy days every year; values as high as 3300mm/year are exceptionally reached, with peaks of up to 365 mm/day (Varese Ligure, 8.11.1982).

The abundance of unstable and easily erodible mudrocks and "chaotic complexes" all along the Apennines favours accelerated erosion and mass-flow processes, leading to high sediment discharge particularly during major flood events, which recur every 20 ÷ 25 years (e.g., Pintus et al., 1985).

The nortwestern apenninic side, drained by tributaries of the Po River, is characterized by much milder slopes (generally below 5%). Major rivers are between 125 and 175 km-long, with drainage areas up to 1700 km^2 or more (e.g., Bormida, Taro, Secchia). Water discharge, showing two maxima in autumn and spring with a pronounced summer drought, reaches mean annual values of 22 ÷ 23 m^3/s (Trebbia, Secchia) to 32 m^3/s (Taro) and maximum annual values up to 465 m^3/s (Trebbia, Taro), with peaks up to 1000 to 1150 m^3/s (Scrivia, Trebbia, Taro).

Climate of the Po Plain is temperate-subcontinental (mean annual temperatures 10° to 14°C; annual excursion 25°C). Annual rainfall progressively increases from Piedmont (Asti: 640mm) and Lombardy (Pavia: 785 mm) towards the Adriatic Sea (Padova: 850mm).

The Northern Apennines and the boundary with the Maritime Alps

The Northern Apennine arc is an accretionary prism grown during steep W-ward subduction of the Adria microplate since the Oligocene, when Cretaceous to Eocene flysches deposited on the Ligurian remnant-ocean floor were thrusted upon the Tuscan Domain, representing the allochtonous sedimentary cover of Adria (e.g., Elter, 1980; Doglioni et al., 1998).

The geologic boundary between the oceanic Ligurian domain and the continental Tuscan domain roughly coincides with the administrative boundary between Liguria and Toscana, with the exception of the two promontories delimiting the La Spezia Gulf, where Tuscan sedimentary successions are exposed (Fig. 2). Within the Ligurid nappes, an internal domain characterized by an oceanic basement with its pelagic sedimentary cover - which has undergone anchizonal deformation during late Paleocene to mid-Eocene slow E-ward subduction (Marroni, 1994; Marroni and Pandolfi, 1996) - is distinguished from an external domain, consisting of detached sheets of unmetamorphosed flysch (Reutter et al., 1982).

The Liguria ophiolites represent the lithospheric remnants of a Tethyan oceanic branch (Ligurian-Piedmont Ocean) which began to open in the Middle Jurassic between Europe and Adria. The ophiolites of the internal domain differ from those of the external domain, and both are distinguished from the Voltri Massif ophiolites, whose western tectonic vergence and high-pressure metamorphism were acquired during alpine subduction.

The eastern boundary of high-pressure metamorphic rocks corresponds to a narrow, N/S-elongated belt including two ophiolite-bearing units and a mainly carbonate sedimentary succession deposited during the Norian/Liassic rifting (Sestri-Voltaggio Zone). These rocks are tectonically sandwiched between the Voltri alpine ophiolites and the Antola Unit, representing the highest thrust-sheet of the Northern Apennine belt. The occurrence of upper Eocene continental to turbiditic sediments unconformably overlying the Voltri Massif, the Sestri-Voltaggio Zone and the Antola Unit indicates that the alpine orogenic prism had been structured and uplifted before the close of the Eocene (e.g., Di Giulio, 1991).

Ophiolites and sedimentary cover

The Internal Ligurid ophiolites - including largely serpentinized cpx-poor depleted peridotites (Bracco Unit) - and the External Ligurid ophiolites - consisting of fertile spinel lherzolites (Casanova Complex) - both differ from typical lithospheric sections generated at mid-ocean ridges. General lack of a sheeted-dyke complex, direct stratigraphic contact between mantle rocks and overlying sediments, and great abundance of Middle Jurassic ophiolitic breccias have suggested either uprise of oceanic lithosphere in transform to slow-spreading ridge settings (e.g., Abbate et al., 1994) or tectonic denudation of sub-continental mantle during break-up (Piccardo et al., 1994). During the mid-Jurassic oceanization, limited and discontinuous production of tholeiitic magmas took place: the largest body of layered Mg-gabbro (Bracco Unit) is over 20 km^2 wide and over 500 m thick, various generations of basaltic dykes occur, and lava flows of massive to pillow basalts locally reach 700 m in thickness; felsic differentiates are very rare (Cortesogno et al., 1987).

Radiolarite sedimentation on the oceanic floor began in the late Middle Jurassic, replaced by Calpionella limestones at the close of the Jurassic. Thinly-interbedded black mudrocks, mudstones and rare quartzarenites (Palombini Shales) accumulated in the middle part of the Cretaceous, followed in the Campanian - when rapid convergence between Africa and Europe began - by very fine-grained turbidites (Val Lavagna Formation) and next in the Maastrichtian to early Paleocene by quartzo-feldspathic turbidite sands derived from the European foreland and deposited in trench settings (Gottero Sandstone; Sestini et al., 1986; Marroni et al., 1992; Marroni & Pandolfi, 1996).

In the apenninic ophiolites, retrograde oceanic metamorphism with growth of mainly greenschist-facies parageneses in the Jurassic was followed by only mild re-equilibration in prehnite-pumpellyite to zeolite facies during subsequent accretion in the orogenic prism (Cortesogno, 1980; Cortesogno et al., 1994).

The Voltri Massif - one of the largest ophiolitic complex of the Alps, including relatively fertile lherzolites (Erro-Tobbio Unit) - consists instead of high-pressure metamorphic rocks (e.g., Piccardo et al., 1997). Basement units of polymetamorphic serpentineschists containing lenses of eclogitic metagabbros commonly retrogressed in greenschist facies, are tectonically associated with cover units including prasinitized metabasalts with glaucophane-bearing blueschist-facies relics, schists and calcschists locally bearing chloritoid.

High-pressure metamorphism also affected the european continental crust, exposed as far east as the Arenzano Massif (Vanossi et al., 1986).

"Basal complexes" and "helminthoid flysches" in the External Ligurid Domain

The tectonic units of the External Ligurids consist of flysch deposits which are invariably detached from their original substratum. The basal part generally consists of tectonically-disrupted Cretaceous dark mudrocks comparable to the Palombini Shales, associated in the SW with dislocated ophiolitic slabs and ophioliticlastic or Europe-derived quartzo-feldspathic turbidites (e.g., Casanova Sandstone; Di Giulio and Geddo, 1990) and in the NE with calclithitic turbidites of austro-alpine affinity (e.g., Salti del Diavolo Conglomerate; upper External Ligurids).

Up to over 2000 m-thick, marly-calcareous turbidites of Campanian to Paleocene age invariably follow (e.g., Antola Fm., Caio Fm., Cassio Fm.). The predominant intrabasinal carbonate fraction was derived from pelagic oozes provisionally accumulated on tectonically active slopes and plateaux, and subsequently resedimented possibly below the carbonate compensation depth on the Ligurid remnant-ocean floor. Quartzo-feldspathic extrabasinal detritus commonly occurs only at the base of turbidite beds (Fontana et al., 1992; 1994). In the lower External Ligurids of the Emilia Apennines, calcareous flysches were deposited until the mid-Eocene (e.g., Farini d'Olmo Fm., Mt. Sporno Fm.).

Piedmont Tertiary Basin and Epiligurid satellite basins

Soon after the mesoalpine orogenic event, rapidly subsident sedimentary basins formed on top of the alpine nappe stack in the west (Torino Hill, Piedmont Tertiary Basin) and on top of the apenninic Ligurid thrust-sheets in the east (Monferrato, Northern Apennine), where - in the rear of the apenninic arcuate front - up to several km-thick terrigenous sequences accumulated.

The Piedmont Tertiary Basin succession begins with largely ophioliticlastic cobble to boulder fanglomerates fed from rapid erosion of the alpine belt (e.g., Molare Fm.; upper Eocene?/lower Oligocene; Gnaccolini, 1995), overlain by hemipelagic mudrocks and quartzo-lithic or litho-quartzose lenticular turbidite bodies mainly derived from continental and oceanic rocks respectively (e.g., Rocchetta-Monesiglio Group.; upper Oligocene/Burdigalian) (Gnaccolini and Rossi, 1994; Gelati and Gnaccolini, 1998). Upper Burdigalian quartzo-lithic turbidites (e.g., Cortemilia Fm.) are followed in the middle Miocene by marls and litho-quartzose metamorphiclastic turbidites (Cessole Marl, Cassinasco Fm.), replaced eastward by quartzo-feldspathic plutoniclastic shelf sandstones (Seravalle Fm.; Caprara et al., 1984). Next, the Tortonian S. Agata Marl is overlain by Messinian evaporitic (Gessoso-Solfifera Fm.) and continental to paralic clastic deposits (Cassano Spinola Conglomerate).

Sedimentary successions deposited in the Epiligurid satellite basins commonly begin with chaotic lenticular units ("basal sedimentary mèlanges"), overlain by hemipelagic marls (Montepiano Fm.; middle/upper Eocene) intertonguing east of the Secchia Valley with up to 1 km-thick quartzo-feldspathic plutoniclastic turbidites (Loiano Fm.). Up to 1 km-thick litho-quartzose turbidites follow (Ranzano Fm.; upper Eocene/lower Oligocene), including three petrologic intervals characterized from base to top by alpine metamorphiclastic, apenninic ophioliticlastic and apenninic carbonaticlastic/alpine metamorphiclastic detritus with episodic supply from active andesitic volcanoes in the upper part (Gazzi and Zuffa, 1970; Cibin, 1993; Zuffa et al., 1995). The upper Oligocene/lower Miocene Antognola Marl unconformably follows, including lenticular turbidites and olistostromes, siliceous and volcaniclastic layers in the upper part. After another major unconformity, the up to 1 km-thick Bismantova Fm. (middle Miocene) consists of transgressive bioclastic hybrid arenites followed by slope mudrocks with slumped horizons and by largely recycled quartzo-lithic to quartzo-feldspathic basinal turbidites (Fontana and Spadafora, 1994). Next, the Tortonian Termina Marl is overlain by Messinian evaporitic (Gessoso-Solfifera Fm.) and continental to paralic clastic deposits.

Foredeeps and Subligurid Units

As a response to steep W-ward subduction of the Adria microplate, a series of foredeeps - the youngest one being the present Po Plain - progressively migrated NE-wards along with the nappe front during the apenninic orogeny (Ricci Lucchi, 1986). These foredeeps have been filled by thick turbidite terrigenous wedges fed at first longitudinally from the Alps and next also transversally from the emergent apenninic ridge (e.g., Gandolfi et al., 1983).

The oldest foredeep sediments are the quartzo-feldspathic plutoniclastic turbidites of the Macigno Fm. (mid-Oligocene/lower Miocene), stratigraphically overlying the Tuscan successions and exposed as far north as the Mt. Zuccone window in the upper Taro River drainage. The upper Oligocene/lower Miocene Cervarola Sandstone - exposed north of the Secchia Valley only in the Bobbio window in the Trebbia River drainage - and the middle Miocene Marnoso-Arenacea Fm. - exposed in the Salsomaggiore structure between the Taro and Stirone Valleys - are still quartzo-feldspathic but with significant metamorphic and sedimentary lithics respectively (Valloni and Zuffa, 1984; Andreozzi and Di Giulio, 1994).

Tectonically sandwiched between the Macigno Fm. of the Tuscan Nappe and the overlying Ligurid thrust-sheets, the composite Subligurid complex includes pelitic to calcareous turbidites of External Ligurid affinity (Canetolo shales and limestones; Paleocene/Eocene) associated with feldspatholithic volcaniclastic sandstones (Petrignacola and Bratica Sandstones; lower Oligocene/lower Miocene?). The nature of the Subligurid Units is debated; they may document the oldest apenninic collisional basin, largely fed by calc-alkalic arc volcanic products (Denecke and Günther, 1981).

CARBONATICLASTIC SANDS RECYCLED FROM LIGURID FLYSCHES

APENNINIC PROVINCE

Framework composition

Detritus transported by apenninic tributaries of the Po River is very rich in calcareous lithics (Lc 36 to 74), with subordinate terrigenous lithics (mainly pelite and - particularly in the Parma Apennine - carbonatic arenite; Lt over 20 only for the Scrivia, Enza and Panaro sands) and quartz (Q over 20 only for the Curone, Stirone and Secchia sands) (Tab. 1; Fig. 3H). Such composition reflects provenance from marly-calcareous turbidites, which are widespread in the Ligurid thrust sheets (e.g.,"helminthoid flysch"). Calcareous rock fragments are mostly recrystallized in sparite, but for several grains the original micritic texture along with ghosts of planktonic foraminifers and sponge spiculae or silicoclastics can be recognized. The Lc peak in the Parma and Baganza sands - the latter also containing some detrital chert - reflects the great abundance in the Parma Apennine of marly-calcareous flysches of both Cretaceous (e.g., Mt. Caio Fm., Mt. Cassio Fm.) and Tertiary age (e.g., Mt. Sporno Fm.).

Ophiolitic detritus (largely cellular serpentinite, with mi-

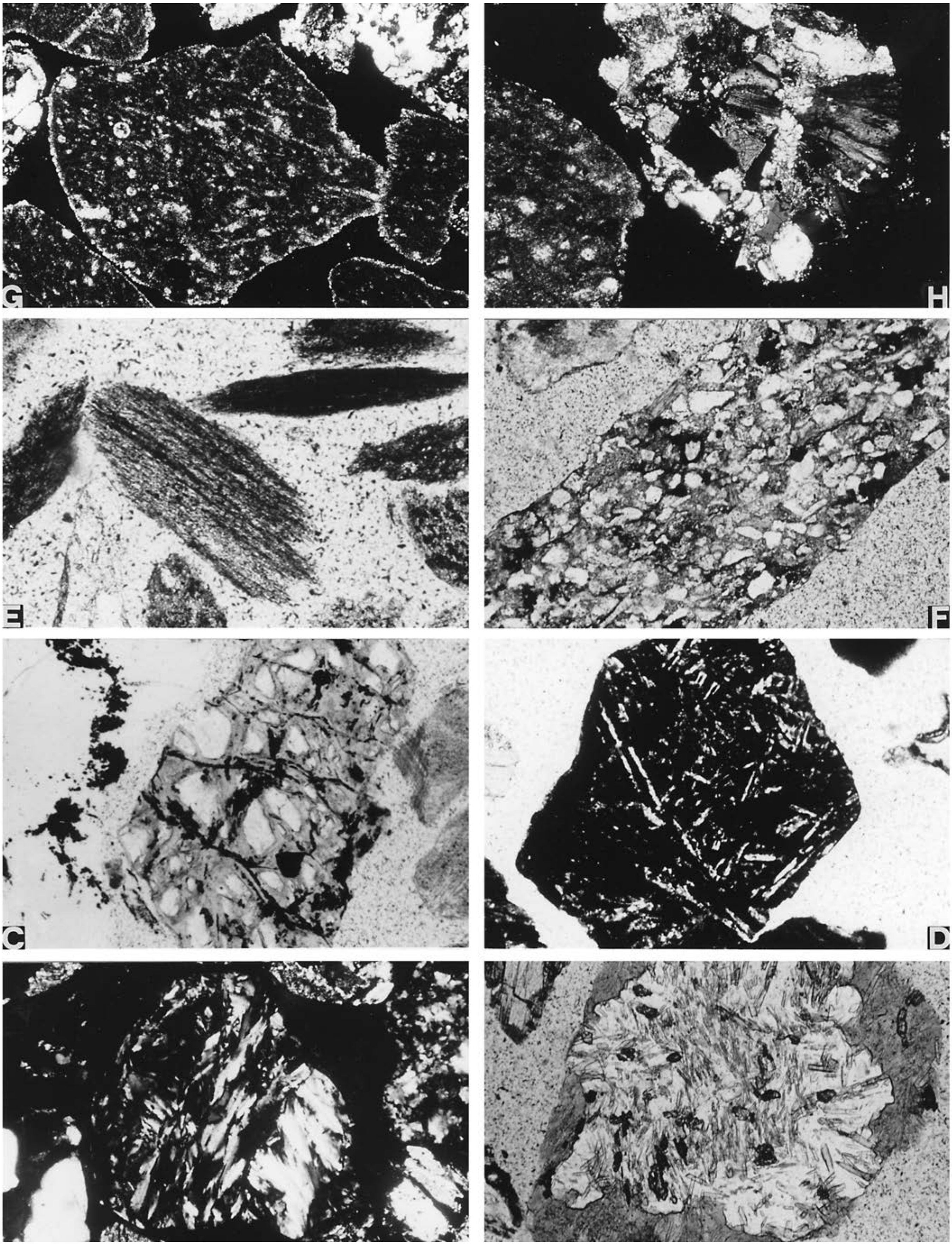

Fig. 3 - Diagnostic grains in modern river and beach sand derived from the Northern Apennines. Alpine metamorphic ophiolite sources : A) serpentineschist grain (Lo; Voltri beach); B) poikiloblastic albite in metabasite grain (Lmb; Teiro River). Internal Ligurid ophiolite sources: C) cellular serpentinite with olivine relics (Lo; Framura beach); D) lathwork basaltic grain (Lv; Framura beach). Internal Ligurid flysch sources: E) slate grain (Lm; Lavagna River); F) siltstone grain (Lt; Vara River). External Ligurid flysch sources: G) pelagic wackestone grain with planktonic fauna (Lc; Camogli beach); H) calcitic sandstone grain (Lt; Taro River, S74). Photos A, G, H with crossed polars. Photos E, H 80x; other photos 40x.

nor lathwork volcanic lithics and chert) is significant for rivers of the northern Emilia Apennines reaching the Liguria/Emilia watershed, where ophiolites associated with the "Basal complexes" of the westernmost External Ligurids are exposed (e.g., Casanova Complex).

The Trebbia sand has almost no quartz and feldspars and few volcanic grains, indicating that recycling of both foredeep clastics comparable to the Cervarola sandstones exposed in the Bobbio window and volcaniclastic sands of the Subligurid Units is negligible. Quartz and feldspars are relatively abundant for the Stirone, a short stream draining mostly the external part of the range, where foredeep successions comparable to the Marnoso-Arenacea and neoautochtonous Plio-Quaternary units are exposed.

A few arkosic terrigenous lithics and plutonic rock fragments are found in river sands from the Reggio and Modena Apennines, where plutoniclastic foredeep successions (Macigno Fm., Cervarola Sandstone) are exposed in the upper drainage. The Secchia sand is considerably richer in quartz and metamorphic lithics than the Enza and Panaro sands, suggesting greater contribution from Epiligurid metamorphiclastic units (e.g., Ranzano Fm., Cibin, 1993). Sand of the Reno River, whose basin includes a variety of quartzo-feldspathic plutoniclastic turbidites belonging to the Ligurid (Mt.Venere/Monghidoro Fms.), Epiligurid (Loiano Fm.) and foredeep successions (Cervarola Sandstone; Tab. 6), is much richer in feldspars and granitoid rock fragments.

River sands from the Pavia Apennines invariably contain some metamorphic lithics. The Scrivia, Curone and Staffora sands also include common serpentineschist grains largely recycled from ophioliticlastic sediments exposed at the easternmost tip of the Piedmont Tertiary Basin and ultimately derived from the Voltri Massif (e.g., Gaggero, p.83, in Zanzucchi, 1994).

Heavy mineral suites

Two different heavy mineral suites are apparent in apenninic river sands (Tab. 2). The Trebbia, Nure and Taro sands are characterized by maximum relative abundance of diallage, enstatite and mainly brown to dark red chromian spinel respectively, derived from External Ligurid ophiolites (e.g., Casanova Complex). Sands of other Emilia rivers are instead characterized by predominance of garnet, with minor amounts of low to high-grade metamorphic (e.g., staurolite in the Secchia sand), ultrastable and titanium minerals (Tab. 3).

This latter suite mostly consists of heavy minerals recycled from Ligurid, Epiligurid and foredeep clastics, as indicated by quite good correspondence of the mean spectrum for major rivers of the Emilia Apennine draining Upper Cretaceous to Neogene synorogenic turbidites (i.e., Enza, Secchia, Panaro), with the grand mean obtained from recalculated data for terrigenous wedges of various ages (Tab. 4). Modern suites tend to be less stable and richer in pyriboles, which are virtually absent in Ligurid flysches and only locally significant in the Epiligurid succession (e.g., upper part of the Ranzano Fm.; Cibin, 1993).

Recycling from turbidites largely fed from the growing alpine orogen explains the overall alpine affinity (e.g., Adda sands; Garzanti et al., 1998) of heavy mineral suites in modern apenninic river sands.

The Pavia and Emilia Apennine river sands are very similar. Only ophiolitic-derived heavy minerals differ: the former - largely derived indirectly from metamorphic alpine ophiolites of the Voltri Massif -, contain more amphiboles (glaucophane, tremolite, actinolite), whereas the latter - derived from unmetamorphosed ophiolites of the External Ligurids - contain more pyroxenes and spinel (Tab. 3).

Zircon is significant in the Enza and Panaro sands. Anatase and brookite are common in the Pavia Apennine and rutile in the Emilia Apennine. Epidotes are common in all samples. The Staffora and Tidone sands are relatively rich in barite.

ANTOLA PROVINCE

Framework composition

River and beach sands in central Liguria (Genova to Rapallo) are largely derived from the Antola "helminthoid flysch", exposed throughout the area.

Composition of beach sands is very close to that of apenninic tributaries of the Po River (Tab. 3). Calcareous rock fragments predominate between Bogliasco and Camogli (mostly cleaved mudstones to wackestones with pelagic faunas; Lc 63 to 74; Fig. 3G); quartz, feldspars, terrigenous and serpentine-bearing grains are more abundant at Genova and S.Margherita.

River sands are similar, but contain greater amounts of non durable metapelitic lithics (slate and phyllite derived from the anchimetamorphic cover of the Internal Ligurids; e.g., Val Lavagna Fm.).

The Zoagli sand, broadly similar to the S.Margherita sand but much richer in serpentine-bearing grains, has been included in the Bracco Province.

Heavy mineral suites

Sands of the Antola Province only loosely compare with those carried by apenninic tributaries of the Po River, being much richer in amphiboles (particularly hornblende) and pyroxenes, and poorer in garnet, high-grade metamorphic, ultrastable and titanium heavy minerals. Garnet is common only in the Bisagno and Sori sands.

Supply from the widely-exposed Antola Fm., which is reported to contain a strongly depleted heavy mineral suite largely consisting of ultrastable grains with some garnet (Rowan, 1990; Fontana et al., 1994), is subordinate. Similarities with the Lavagna sand upstream from the confluence with the Sturla River indicate important supply from Internal Ligurid flysches (e.g., Val Lavagna Fm.). The Genova sand contains amphiboles (including tremolite and glaucophane) and pyroxenes derived directly or indirectly from the Voltri Massif.

OPHIOLITICLASTIC SANDS DERIVED FROM LIGURIA OPHIOLITES

VOLTRI PROVINCE

Framework composition

Sands of the Bormida River tributaries, draining the metamorphic alpine ophiolites of the Voltri Massif, are very rich in serpentineschist grains and contain abundant metamorphic lithics (including metapelite, metafelsite and metabasite grains derived from prasinitized basalts and calcschists of the Voltri Massif). Only the Lemme sands contain a few cellular serpentinite grains and sedimentary lithics derived from the Sestri/Voltaggio Zone.

Table 1 - Framework composition of modern river and beach sands.

river	site	sample	grain size (microns)	grain size (phi units)	monocrystalline quartz	polycrystalline quartz	plagioclase	alkalifeldspars	felsic volcanic lithics	mafic volcanic lithics	felsic plutonic lithics	mafic plutonic lithics	limestone grains	dolostone grains	terrigenous lithics	cherty lithics	metapelitic lithics	metafelsitic lithics	metabasitic lithics	serpentine grains	micas	heavy minerals	Cl grains (allochems)	NCl grains	anthropic grains	alterite and n.n.	TOTAL	Q	F	Lv	Lc	Lt	Lch	Lm	Lo	TOTAL	Qp/Q	P/F	Lvm/Lv	Lcd/Lc	Lmb/Lm	Loc/Lo
BORMIDA BASIN																																										
Bormida Milles.	Cortemilia	S 19	220	2,2	20	22	3	4	0	0	0	0	9	0	9	0	23	1	1	4	0	0	0	1	0	1	100,0	44	7	0	11	7	0	26	4	100,0	52	47	n.d.	0	6	n.d.
Bormida Spigno	Mombaldone	S 18	410	1,3	11	14	2	1	0	0	0	0	8	0	11	0	21	0	5	20	0	1	0	3	0	2	100,0	26	4	0	12	8	0	28	21	100,0	57	n.d.	n.d.	0	18	6
Bormida	Acqui Terme	S174	450	1,2	12	28	0	4	0	0	1	0	7	0	11	0	10	7	5	12	0	2	0	0	0	1	100,0	43	8	0	10	5	0	20	13	100,0	69	20	n.d.	0	24	4
Bormida	Alessandria	S176	950	0,1	9	23	1	2	0	2	1	0	0	0	2	0	3	7	6	42	0	0	0	0	0	1	100,0	36	6	2	0	1	0	13	43	100,0	72	40	n.d.	n.d.	38	1
Erro	Melazzo	S173	600	0,7	4	9	2	0	0	0	1	0	2	0	2	0	8	9	12	48	1	0	0	0	0	2	100,0	18	6	0	2	2	0	22	50	100,0	70	n.d.	n.d.	n.d.	41	1
Orba	Capriata	S175	500	1,0	9	6	2	3	0	0	1	0	2	0	1	0	9	5	12	45	0	3	0	0	0	1	100,0	19	7	0	2	1	0	24	47	100,0	41	42	n.d.	n.d.	46	1
Lemme	Carrosio	S 11	800	0,3	1	21	0	1	1	0	0	0	4	0	6	4	15	0	4	35	0	0	0	0	0	9	100,0	24	1	1	5	6	4	20	39	100,0	94	n.d.	n.d.	n.d.	20	11
APENNINIC RIVERS																																										
Scrivia	Tortona	S 21	310	1,7	12	6	3	3	0	1	0	0	31	0	25	0	2	0	2	9	0	2	0	1	0	3	100,0	19	6	1	36	23	0	4	10	100,0	34	45	n.d.	0	n.d.	5
Curone	Volpedo	S 91	350	1,5	13	8	3	1	1	0	4	0	33	1	15	0	3	3	0	10	0	1	0	0	1	4	100,0	24	7	1	42	10	0	6	11	100,0	36	n.d.	n.d.	2	n.d.	30
Staffora	Rivanazzano	S 92	300	1,7	9	7	1	3	0	0	0	0	48	0	16	0	0	3	1	9	0	1	0	0	0	1	100,0	18	5	0	55	10	0	4	9	100,0	42	n.d.	n.d.	0	n.d.	48
Tidone	Corano	S 93	520	0,9	9	3	3	2	1	0	2	0	44	0	23	1	4	4	1	3	0	0	0	0	0	4	100,0	14	7	1	48	19	1	8	3	100,0	26	40	n.d.	0	8	n.d.
Trebbia	Rivalta	S 94	400	1,3	1	1	1	0	0	3	0	0	39	1	17	3	4	0	3	26	0	1	0	0	0	0	100,0	1	1	3	45	13	3	7	27	100,0	n.d.	n.d.	100	3	n.d.	90
Nure	Pontenure	S 77	310	1,7	4	1	1	0	0	2	0	0	48	3	20	0	0	0	2	14	0	2	0	0	0	3	100,0	7	1	2	57	16	0	2	15	100,0	n.d.	n.d.	n.d.	6	n.d.	88
Arda	Fiorenzuola	S 76	165	2,6	13	4	1	0	0	0	0	0	57	1	19	1	0	0	0	3	0	1	0	0	0	0	100,0	18	1	0	62	15	1	0	3	100,0	23	n.d.	n.d.	3	n.d.	n.d.
Stirone	Fidenza	S 75	185	2,4	27	6	3	4	0	0	0	0	44	0	10	0	0	0	0	2	0	0	0	0	0	2	100,0	34	7	0	46	10	0	0	2	100,0	17	n.d.	n.d.	0	n.d.	n.d.
Ceno	Fornovo	S221	400	1,3	3	4	2	1	1	1	1	0	45	0	29	1	2	1	0	7	0	1	0	0	1	1	100,0	8	4	2	58	18	1	2	7	100,0	n.d.	n.d.	n.d.	0	n.d.	n.d.
Taro	Fornovo	S649	570	0,8	2	1	2	1	0	2	1	0	40	1	38	0	3	3	0	7	0	0	0	0	0	0	100,0	5	3	2	49	29	0	5	7	100,0	n.d.	n.d.	n.d.	1	n.d.	n.d.
Taro	Pontetaro	S 74	300	1,7	7	5	3	4	0	3	1	0	33	0	20	0	2	1	0	9	1	0	0	0	3	7	100,0	15	9	5	43	15	0	3	10	100,0	44	45	100	0	n.d.	85
Baganza	Parma	S 79	310	1,7	5	1	1	0	0	0	0	0	63	0	14	6	0	1	0	5	0	1	0	0	0	4	100,0	8	1	0	70	10	6	1	5	100,0	n.d.	n.d.	n.d.	0	n.d.	n.d.
Parma	Parma	S78	140	2,8	8	4	0	0	0	0	0	0	69	0	14	1	0	0	0	2	0	0	0	0	1	3	100,0	13	0	0	74	8	1	0	3	100,0	32	n.d.	n.d.	0	n.d.	n.d.
Enza	S.Ilario	S 73	235	2,1	4	6	3	3	0	1	3	0	46	0	28	0	1	0	0	2	0	3	0	0	0	1	100,0	14	7	1	53	22	0	1	2	100,0	59	45	n.d.	0	n.d.	n.d.
Secchia	Modena	S 72	190	2,4	20	6	3	3	0	0	0	0	39	0	20	1	0	8	0	0	0	0	0	0	0	1	100,0	31	6	0	40	15	1	7	0	100,0	24	n.d.	n.d.	0	n.d.	n.d.
Panaro	Spilamberto	S 70	310	1,7	8	4	3	3	0	0	1	0	46	0	30	1	1	0	0	0	0	1	0	0	0	3	100,0	14	7	0	51	27	1	1	0	100,0	35	n.d.	n.d.	0	n.d.	n.d.
Reno	Bologna	S 71	580	0,8	16	15	4	9	0	0	7	0	24	1	21	0	1	0	0	0	0	1	0	1	0	1	100,0	34	19	0	28	18	0	1	0	100,0	49	35	n.d.	3	n.d.	n.d.
LIGURIA RIVERS																																										
Teiro	Varazze	S654	550	0,9	1	13	12	0	0	0	2	0	0	1	0	1	19	7	20	18	0	2	0	2	0	1	100,0	17	17	0	1	0	1	45	19	100,0	92	89	n.d.	n.d.	43	n.d.
Arrestra	Cogoleto	S148	380	1,4	3	4	4	1	1	0	3	0	1	1	1	0	11	13	10	42	0	6	0	0	0	1	100,0	16	7	1	2	0	0	26	47	100,0	58	60	n.d.	n.d.	30	0
Cerusa	Voltri	S144	520	0,9	3	6	1	1	0	0	4	0	0	1	0	0	16	13	8	42	0	5	0	0	1	1	100,0	16	7	0	1	0	0	29	46	100,0	71	55	n.d.	n.d.	22	0
Varenna	Pegli	S142	500	1,0	1	1	1	0	0	1	1	0	2	0	3	0	15	14	7	54	1	1	0	0	0	1	100,0	5	3	1	4	1	0	31	55	100,0	n.d.	n.d.	n.d.	n.d.	20	0
Polcevera	Genova	S150	425	1,2	9	18	2	0	0	1	1	0	8	2	18	0	21	3	3	12	0	0	0	0	1	3	100,0	28	4	1	13	15	0	27	12	100,0	66	n.d.	n.d.	19	10	15
Bisagno	Genova	S152	450	1,2	4	6	1	0	0	0	0	0	48	2	21	0	10	2	1	3	0	0	0	0	1	3	100,0	13	1	0	53	19	0	12	3	100,0	58	n.d.	n.d.	3	4	n.d.
Sturla	Genova	S166	600	0,7	5	11	1	3	1	3	1	0	33	1	18	0	11	4	1	5	0	1	0	0	0	2	100,0	19	5	4	36	18	0	13	5	100,0	69	n.d.	83	4	4	n.d.
Recco	Recco	S169	570	0,8	5	11	3	2	0	0	1	0	36	0	14	0	19	1	0	3	0	0	0	0	0	6	100,0	19	6	0	38	13	1	20	3	100,0	71	60	n.d.	0	0	n.d.
Sturla	S.Pietro	S650	520	0,9	6	5	0	1	0	3	1	0	2	0	10	1	47	5	2	17	0	1	0	0	0	1	100,0	13	2	3	3	9	1	52	17	100,0	47	n.d.	100	n.d.	3	75
Lavagna	S.Pietro	S 651	230	2,1	7	0	1	1	0	0	0	0	3	0	16	0	56	15	2	0	0	1	0	1	0	0	100,0	9	1	0	3	16	0	71	0	100,0	n.d.	n.d.	n.d.	n.d.	2	n.d.
Lavagna	Carasco	S113	260	1,9	2	6	1	0	0	1	0	0	2	0	12	0	64	2	1	7	0	0	0	0	0	2	100,0	9	1	1	3	11	1	67	7	100,0	n.d.	n.d.	n.d.	n.d.	1	n.d.
Graveglia	Graveglia	S112	370	1,4	3	2	1	0	0	1	0	0	11	0	15	3	24	0	1	34	0	0	0	0	0	2	100,0	6	2	1	12	16	4	25	34	100,0	n.d.	n.d.	n.d.	4	4	75
Entella	Chiavari	S 44	620	0,7	4	4	1	2	0	8	0	0	6	0	25	0	13	0	4	20	1	1	0	1	2	9	100,0	9	3	9	7	29	0	20	24	100,0	n.d.	n.d.	100	n.d.	22	65
Gromolo	Sestri Levante	S652	650	0,6	0	3	1	0	0	1	1	0	1	0	14	3	25	2	2	47	0	0	0	0	0	0	100,0	3	2	1	1	14	3	28	47	100,0	n.d.	n.d.	n.d.	n.d.	8	65
Petronio	Riva Trigoso	S105	520	0,9	3	3	6	2	0	5	1	2	2	0	16	1	12	3	8	33	0	2	0	0	0	3	100,0	7	10	7	3	16	1	23	34	100,0	n.d.	79	100	n.d.	36	65
Castagnola	Deiva	S106	360	1,5	4	1	6	1	0	0	1	3	5	0	14	0	32	1	1	29	0	3	0	0	0	1	100,0	5	8	2	5	15	0	35	31	100,0	n.d.	86	n.d.	n.d.	2	77
Ghiaiaro	Levanto	S110	360	1,5	2	0	4	1	0	0	1	1	1	1	38	0	33	1	0	18	0	0	0	0	0	2	100,0	3	5	0	2	37	0	34	19	100,0	n.d.	90	n.d.	n.d.	0	50
Vara	Padivarma	S 54	740	0,4	8	3	6	3	0	1	5	0	9	0	26	2	5	1	3	10	1	0	0	0	7	10	100,0	18	15	1	13	29	3	9	12	100,0	26	68	n.d.	0	33	80
Vara	Ceparana	S131	540	0,9	7	6	4	3	0	0	5	0	6	0	35	1	13	1	0	17	0	0	0	0	0	2	100,0	19	11	0	6	32	1	13	17	100,0	48	50	n.d.	n.d.	0	57
LIGURIA BEACHES																																										
	Celle	S146	525	0,9	9	21	2	0	0	0	5	0	2	9	5	0	11	20	6	12	0	0	0	0	0	1	100,0	30	6	0	13	2	0	37	12	100,0	70	n.d.	n.d.	85	16	0
	Varazze	S147	505	1,0	1	11	7	0	0	0	3	0	2	0	1	0	14	25	14	21	0	1	0	0	0	1	100,0	20	12	0	2	1	0	44	22	100,0	91	95	n.d.	n.d.	26	0
	Cogoleto	S149	415	1,3	4	8	2	0	0	1	0	0	2	12	4	0	7	3	6	35	0	4	1	0	2	10	100,0	15	2	1	19	2	0	19	42	100,0	67	n.d.	n.d.	83	37	0
	Arenzano	S145	530	0,9	9	9	3	2	0	0	1	1	0	5	9	1	6	10	2	40	1	0	0	0	1	2	100,0	23	8	0	8	5	1	14	42	100,0	50	80	n.d.	100	9	0
	Voltri	S143	405	1,3	7	9	3	1	0	1	0	0	3	4	3	1	13	11	4	34	0	3	1	0	0	3	100,0	21	5	1	8	2	1	25	37	100,0	57	n.d.	n.d.	58	14	0
	Genova	S151	360	1,5	11	10	2	2	0	0	3	0	27	2	22	0	2	2	1	7	0	1	1	0	0	10	100,0	25	6	0	34	22	0	5	8	100,0	48	60	n.d.	6	n.d.	15
	Bogliasco	S167	470	1,1	7	6	1	2	2	2	2	0	55	1	8	0	1	2	2	5	0	0	5	0	0	1	100,0	14	5	3	63	5	0	5	5	100,0	46	n.d.	50	1	n.d.	n.d.
	Sori	S168	480	1,1	8	7	0	1	1	2	1	1	56	1	11	0	1	4	1	3	0	1	0	0	0	2	100,0	17	2	2	64	5	1	6	3	100,0	45	n.d.	n.d.	2	n.d.	n.d.
	Camogli	S170	475	1,1	3	3	1	1	0	0	1	0	68	0	16	1	0	2	1	2	0	1	1	0	0	2	100,0	7	3	0	74	13	1	1	2	100,0	n.d.	n.d.	n.d.	0	n.d.	n.d.
	S. Margherita	S171	1000	0,0	9	7	2	2	2	4	2	0	25	0	25	4	1	3	2	8	0	0	2	0	0	5	100,0	19	8	6	28	22	4	6	8	100,0	45	53	71	0	n.d.	n.d.
	Zoagli	S172	1000	0,0	2	3	2	0	0	4	1	2	23	0	17	2	3	0	2	31	1	0	0	0	0	7	100,0	6	1	5	25	17	4	7	34	100,0	n.d.	n.d.	93	0	n.d.	60
	Chiavari	S101	430	1,2	6	7	2	1	1	6	0	1	14	0	27	2	13	2	1	18	0	1	0	0	1	0	100,0	17	2	6	16	25	2	15	18	100,0	54	n.d.	92	0	3	70
	Sestri Levante	S102	340	1,6	23	7	8	1	1	4	2	0	2	0	9	4	12	5	1	19	1	1	0	0	0	1	100,0	33	10	6	2	9	4	16	20	100,0	24	82	80	n.d.	3	50
	Riva Trigoso	S104	375	1,4	9	5	10	3	0	13	0	4	1	0	12	1	4	4	6	24	0	4	0	0	2	2	100,0	15	15	15	2	12	1	13	28	100,0	35	80	100	n.d.	43	100
	Moneglia	S103	350	1,5	25	12	5	3	0	0	4	0	5	0	29	1	9	5	0	1	0	1	0	0	0	3	100,0	42	10	0	10	23	1	13	1	100,0	32	67	n.d.	0	0	n.d.
	Deiva	S107	435	1,2	5	7	15	3	0	0	1	12	3	0	12	2	4	5	3	17	0	4	0	0	1	7	100,0	16	24	3	3	13	2	11	28	100,0	59	77	n.d.	n.d.	27	50
	Framura	S108	620	0,7	0	0	1	0	0	16	1	0	10	0	5	0	2	1	9	49	0	1	0	0	0	6	100,0	1	1	17	12	4	0	14	52	100,0	n.d.	n.d.	100	0	78	70
	Bonassola	S109	360	1,5	2	2	12	1	0	3	1	4	5	0	3	1	3	2	4	28	1	4	0	0	0	24	100,0	4	41	3	6	3	1	9	34	100,0	n.d.	97	n.d.	n.d.	44	60
	Levanto	S111	480	1,1	4	3	11	1	0	0	5	4	2	0	21	1	7	1	0	34	0	3	0	0	0	0	100,0	11	22	1	3	20	1	8	36	100,0	44	92	n.d.	n.d.	5	80
	Monterosso	S133	1000	0,0	0	0	36	1	0	0	10	15	5	0	17	0	3	0	3	6	0	0	0	0	0	1	100,0	3	50	13	7	14	0	6	6	100,0	n.d.	96	n.d.	n.d.	n.d.	n.d.

Grain size (median diameter) is expressed both in microns and phi units; n.d.= not determined (if number of counted grains is under 10 - internal ratios give at best only semiquantitative information when calculated on a limited number of grains). Indexes explained in text.

Table 2 - Transparent heavy minerals (density > 2,84).

river	site	sample	grain size (phi units)	acid treatments	HM% VFS-FS	% transparent	% opaque	% turbid	zircon	tourmaline	rutile	sphene	anatase	brookite	apatite	barite	hornblende	glaucophane	tremolite/actinolite	other amphiboles	augite	diallage	diopside	other clinopiroxenes	enstatite	hyperstene	olivine	spinel	epidote	zoisite	clinozoisite	pumpellyite	chloritoid	garnet	staurolite	andalusite	kyanite	sillimanite	TOTAL	ZTR	T&O	Hb	AA	CPX	OPX	OS	LgM	Gt	HgM	TOTAL
BORMIDA BASIN																																																		
Bormida Millesim	Cortemilia	S 19	2,0	HCl	3,7	66%	34%	n.d.	1	10	1	1	1	0	0	0	21	12	4	0	0	0	0	1	1	1	0	0	26	0	1	0	4	15	1	0	1	1	100,0	11	2	21	16	1	2	0	31	15	3	100,0
Bormida	Alessandria	S176	0,0	HCl	6,8	71%	14%	15%	0	1	1	1	1	2	1	1	10	15	16	0	0	5	1	3	4	0	0	0	18	3	4	0	1	16	0	1	0	0	100,0	1	5	10	31	9	4	0	26	16	1	100,0
Orba	Capriata	S175	1,0	Ac	11,9	56%	16%	27%	0	1	0	2	0	0	0	0	11	3	31	1	0	7	0	0	8	4	0	1	16	9	3	0	2	5	0	0	0	0	100,0	1	2	11	35	7	12	1	29	5	0	100,0
Lemme	Carrosio	S 11	0,3	HCl	10,0	57%	22%	21%	0	0	2	4	0	1	1	1	15	15	7	2	1	3	2	3	11	1	0	1	17	1	1	0	1	11	0	0	2	2	100,0	2	7	15	24	8	12	1	20	11	4	100,0
APENNINIC RIVERS																																																		
Scrivia	Tortona	S 21	1,7	HCl	6,0	77%	23%	n.d.	1	0	4	3	2	5	0	2	9	5	4	2	1	1	0	0	0	2	0	0	13	1	1	0	2	44	0	0	1	1	100,0	5	11	9	11	2	2	0	17	44	2	100,0
Curone	Volpedo	S 91	1,8	HCl	7,0	65%	15%	20%	0	1	0	2	1	1	0	4	12	5	3	1	0	1	1	0	1	1	0	0	17	0	2	0	0	48	0	2	2	0	100,0	1	7	12	8	2	1	0	19	48	4	100,0
Staffora	Rivanazzanc	S 92	2,0	HCl	6,2	62%	29%	10%	3	1	2	2	1	2	0	12	5	4	6	0	0	1	0	0	1	0	0	0	6	2	1	0	0	53	1	1	1	0	100,0	5	16	5	10	1	1	0	9	53	2	100,0
Tidone	Corano	S 93	1,1	HCl	3,8	52%	38%	10%	1	3	3	2	0	2	0	13	8	3	3	1	0	0	1	0	1	0	1	3	11	1	1	0	2	43	2	0	1	0	100,0	6	17	8	7	1	1	3	14	43	3	100,0
Trebbia	Rivalta	S 94	1,3	HCl	5,0	50%	36%	14%	1	0	4	1	0	0	0	1	2	1	3	0	5	23	8	0	1	3	0	10	20	0	2	0	0	14	2	1	1	1	100,0	4	2	2	3	36	4	10	22	14	5	100,0
Nure	Pontenure	S 77	2,0	HCl	3,4	57%	28%	15%	1	1	0	1	1	0	0	0	8	0	2	0	1	20	14	0	21	2	1	18	8	1	1	0	0	2	0	1	0	1	100,0	2	2	8	2	35	23	19	9	2	1	100,0
Taro	Pontetaro	S 74	1,9	HCl	0,6	50%	40%	10%	2	1	3	3	0	0	0	3	5	1	1	1	1	7	2	0	2	4	0	29	10	2	3	0	1	20	3	0	0	1	100,0	5	5	5	2	10	6	29	15	20	4	100,0
Enza	S.Ilario	S 73	2,0	HCl	1,0	62%	34%	4%	8	1	8	2	0	1	0	8	3	3	1	0	0	1	1	0	2	1	0	3	11	4	2	0	1	46	1	0	0	0	100,0	17	10	3	3	2	2	3	16	46	1	100,0
Secchia	Modena	S 72	2,1	HCl	3,6	38%	40%	22%	1	2	3	2	0	0	0	5	13	0	1	1	0	2	3	0	1	4	0	3	5	1	1	0	0	45	8	0	1	1	100,0	5	7	13	2	5	5	3	7	45	10	100,0
Panaro	Spilamberto	S 70	1,8	HCl	1,7	55%	33%	12%	6	1	5	1	0	1	0	4	8	1	1	0	0	1	1	0	1	0	0	8	6	3	2	0	1	47	3	0	0	1	100,0	12	6	8	1	1	1	8	12	47	4	100,0
LIGURIA RIVERS																																																		
Arrestra	Cogoleto	S148	1,2	---	34,3	65%	13%	22%	0	1	0	2	0	0	0	0	8	0	52	0	0	7	5	0	6	2	0	0	3	8	6	0	0	4	0	0	0	0	100,0	1	2	8	52	12	8	0	16	4	0	100,0
Varenna	Pegli	S142	1,6	HCl	9,4	44%	40%	16%	0	1	0	2	0	1	0	1	6	6	15	2	0	23	12	0	12	3	1	0	9	1	2	0	0	7	1	0	0	0	100,0	1	3	6	22	35	15	1	12	7	1	100,0
Polcevera	Genova	S150	0,3	Ac	0,6	61%	12%	27%	0	0	1	2	0	1	0	0	9	3	13	1	0	21	8	0	4	4	3	3	3	2	6	1	0	19	1	0	0	0	100,0	1	3	9	17	29	7	5	11	19	1	100,0
Bisagno	Genova	S152	0,8	HCl	3,1	52%	22%	26%	0	1	2	2	1	0	0	1	25	3	6	1	0	4	2	0	1	1	0	1	11	3	6	0	1	32	2	1	0	0	100,0	2	3	25	9	6	2	1	20	32	3	100,0
Lavagna	S.Pietro	S651	2,2	HCl	0,2	66%	16%	19%	12	1	3	2	9	0	0	0	14	2	12	1	0	3	6	0	6	5	0	0	9	0	0	0	0	16	0	0	0	1	100,0	16	11	14	15	9	11	0	9	16	1	100,0
Lavagna	Carasco	S113	2,0	---	0,4	51%	18%	31%	4	0	0	1	1	1	0	0	6	2	1	0	0	22	18	0	6	11	2	1	14	2	2	0	1	9	0	0	0	0	100,0	4	3	6	2	39	17	3	19	9	0	100,0
Entella	Chiavari	S 44	0,7	---	0,6	63%	17%	20%	2	0	0	0	1	1	0	0	21	0	3	1	1	35	11	0	6	1	6	1	6	2	0	0	0	3	0	0	0	0	100,0	2	2	21	4	47	7	7	8	3	0	100,0
Petronio	Riva Trigoso	S105	0,9	---	6,7	51%	11%	38%	0	0	0	0	0	0	0	0	12	1	7	1	0	29	12	0	0	21	1	3	8	2	2	1	0	3	0	0	0	0	100,0	0	0	12	8	41	21	3	13	3	0	100,0
Castagnola	Deiva	S106	1,4	Ac	6,6	85%	9%	6%	0	0	0	0	0	0	0	0	2	0	0	0	1	87	4	0	0	5	1	0	1	0	0	0	0	2	0	0	0	0	100,0	0	0	2	0	91	5	1	1	2	0	100,0
Vara	Ceparana	S131	0,9	Ac	0,7	88%	7%	5%	0	1	0	0	0	0	0	0	6	0	0	0	1	69	6	0	9	1	2	1	4	0	0	0	0	3	0	0	0	0	100,0	1	0	6	0	75	10	2	4	3	0	100,0
LIGURIA BEACHES																																																		
	Arenzano	S145	1,2	---	6,3	48%	14%	38%	0	1	1	1	0	1	0	0	18	1	17	1	0	8	7	1	4	3	2	2	7	6	7	0	0	18	0	1	0	0	100,0	1	2	18	18	15	7	4	19	18	1	100,0
	Voltri	S143	1,3	---	26,4	55%	14%	32%	0	2	1	3	0	1	0	0	12	4	19	1	0	11	2	0	10	5	1	0	5	3	6	0	3	15	1	0	0	0	100,0	2	4	12	24	13	15	1	16	15	1	100,0
	Genova	S151	1,4	Ac	0,5	57%	13%	29%	0	1	1	2	0	1	0	0	24	6	19	1	0	6	4	0	16	3	1	2	6	2	4	0	0	5	0	0	1	0	100,0	2	2	24	26	10	19	3	11	5	1	100,0
	Sori	S168	1,0	Ac	2,4	50%	15%	35%	0	0	1	1	1	1	0	1	20	2	6	1	1	10	5	0	5	5	2	3	8	1	1	1	0	25	1	0	0	0	100,0	1	3	20	9	15	11	4	10	25	1	100,0
	Chiavari	S101	1,2	Ac	2,4	26%	5%	69%	0	0	0	0	1	0	0	0	27	1	15	1	0	18	14	0	4	11	1	1	5	1	1	0	0	1	0	0	0	0	100,0	0	1	27	16	32	15	2	7	1	0	100,0
	Sestri Levant	S102	2,4	HCl	1,7	53%	23%	25%	0	0	1	0	0	0	0	0	19	0	3	1	2	33	10	0	6	5	3	2	9	4	2	0	0	4	0	0	0	0	100,0	1	0	19	4	45	10	4	15	4	0	100,0
	Bonassola	S109	1,3	Ac	9,5	86%	9%	4%	0	0	0	0	0	0	0	0	6	0	0	0	0	88	2	0	0	1	0	2	1	0	2	0	0	1	0	0	0	0	100,0	0	0	6	0	89	1	2	2	1	0	100,0
	Levanto	S110	1,1	---	10,6	53%	14%	32%	0	0	0	1	0	0	0	0	32	0	1	2	0	34	10	0	2	11	2	0	3	0	1	0	0	0	0	0	0	0	100,0	0	1	32	3	45	13	2	4	0	0	100,0
	Monterosso	S133	-0,1	Ac	4,5	70%	6%	24%	0	0	0	0	1	0	0	0	22	0	4	2	1	58	4	0	2	3	0	0	3	1	1	0	0	2	0	0	0	0	100,0	0	1	22	6	62	5	0	4	2	0	100,0

“Other amphiboles” mostly include antophyllite. HM% VFS-FS= percent heavy minerals in the studied 63-250 micron fraction. HCl = chloridric acid; Ac= acetic acid. Indexes explained in text;

Table 3 - Areas characterized by homogeneous sand composition in Liguria and the Northern Apennines.

AREAS	N	grain size	Q	F	Lv	Lc	Lt	Lch	Lm	Lo	TOTAL	Qp/Q	P/F	Lcd/Lc	Lmb/Lm	Loc/Lo	N	HM%FS	ZTR	T&O	Hb	AA	CPX	OPX	OS	LgM	Gt	HgM	TOTAL
BORMIDA BASIN																													
BORMIDA - upper drainage	3	1,5	38	6	0	11	7	0	25	13	100,0	60	33	0	16	5	1	3,7	11	2	21	16	1	2	0	31	15	3	100,0
Bormida Millesimo/Bormida Spigno		0,6	10	2	0	1	1	0	4	9		9	19	0	10	1													
Right tributaries of Bormida R.	3	0,7	20	5	0	3	3	1	22	45	100,0	68	42	n.d.	36	4	2	9,6	1	4	12	30	8	9	1	25	10	1	100,0
Erro/Orba/Lemme		0,3	3	3	1	2	3	2	2	6		27			14	5		2,6	0	3	3	5	1	4	1	5	6	2	
BORMIDA - lower drainage	1	0,1	36	6	2	0	1	0	13	43	100,0	72	40	n.d.	38	1	1	6,8	1	5	10	31	9	4	0	26	16	1	100,0
NORTHERN APENNINES																													
PAVIA APENNINE	4	1,5	19	6	0	45	15	0	6	8	100,0	35	43	0	8	28	4	5,7	4	13	8	9	1	1	1	14	47	3	100,0
Scrivia/Curone/Staffora/Tidone		0,4	4	1	0	8	7	0	2	4		6	4	1		22		1,4	2	5	3	2	1	0	2	4	5	1	
PIACENZA APENNINE	2	1,5	4	1	3	51	14	1	5	21	100,0	n.d.	n.d.	5	n.d.	89	2	4,2	3	2	5	2	35	13	15	15	8	3	100,0
Trebbia/Nure		0,3	4	0	1	8	2	2	4	9				2		1		1,1	2	0	4	1	1	13	6	9	8	2	
EMILIA APENNINE																													
Arda/Stirone	2	2,5	26	4	0	54	13	0	0	3	100,0	20	n.d.	1	n.d.	n.d.													
		0,1	11	4	0	11	4	1	0	0		4		2															
Ceno/Taro	3	1,3	10	5	3	50	21	0	3	8	100,0	44	45	0	n.d.	85	1	0,6	5	5	5	2	10	6	29	15	20	4	100,0
		0,5	5	3	2	8	7	1	2	2				1															
Parma/Baganza/Enza/Secchia/Panaro	5	2,1	16	4	0	57	16	2	2	2	100,0	38	45	0	n.d.	n.d.	3	2,1	11	7	8	2	3	2	4	12	46	5	100,0
		0,5	9	4	0	14	8	2	3	2		15		0				1,3	6	2	5	1	2	2	3	5	1	5	
Reno	1	0,8	34	19	0	28	18	0	1	0	100,0	49	35	3	n.d.	n.d.	1*	3,8	2	4	14	1	4	2	0	23	45	7	100,0
LIGURIA																													
CELLE/VARAZZE - rivers (Teiro)	1	0,9	17	17	0	1	0	1	45	19	100,0	92	89	n.d.	43	n.d.													
CELLE/VARAZZE - beaches	2	1,0	25	9	0	7	1	0	40	17	100,0	81	95	85	21	0													
		0,0	7	4	0	8	1	0	5	7		15			7	0													
VOLTRI - rivers																													
Arrestra/Cerusa/Varenna	3	1,1	13	6	0	2	1	0	29	49	100,0	64	57	n.d.	24	0	2	22	1	2	7	37	23	11	0	14	5	0	100,0
		0,2	7	2	0	1	1	0	2	5		9	4		5	0		18	0	1	1	21	16	5	0	2	2	0	
Polcevera	1	1,2	28	4	1	13	15	0	27	12	100,0	66	n.d.	19	10	15	1	0,6	1	3	9	17	29	7	5	11	19	1	100,0
VOLTRI - beaches	3	1,2	20	5	0	11	3	1	19	40	100,0	58	80	81	20	0	2	16	2	3	15	21	14	11	2	17	16	1	100,0
Cogoleto/Arenzano/Voltri		0,2	4	3	0	6	2	1	6	3		8		21	15	0		14	1	1	4	4	2	6	2	2	2	0	
ANTOLA - rivers	3	0,9	17	4	1	42	17	0	15	4	100,0	66	60	2	3	n.d.	1	3,1	2	3	25	9	6	2	1	20	32	3	100,0
Bisagno/Sturla/Recco		0,2	4	3	2	9	3	0	5	1		7		2	2														
ANTOLA - beaches																													
Genova	1	1,5	25	6	0	34	22	0	5	8	100,0	48	60	6	n.d.	15	1	0,5	2	2	24	26	10	19	3	11	5	1	100,0
Bogliasco/Sori/Camogli	3	1,1	13	3	2	67	8	0	4	3	100,0	45	n.d.	1	n.d.	n.d.	1	2,4	1	3	20	9	15	11	4	10	25	1	100,0
		0,0	5	2	2	6	5	0	3	2		1		1															
S.Margherita	1	0,0	19	8	6	28	22	4	6	8	100,0	45	53	0	n.d.	n.d.													
BRACCO - rivers																													
Lavagna/Sturla	3	1,7	10	1	2	3	12	1	63	8	100,0	47	n.d.	n.d.	2	75	2	0,3	10	7	10	9	24	14	2	14	12	0	100,0
		0,6	2	0	2	0	3	1	10	9					1			0,1	9	6	6	9	21	4	2	7	5	0	
Graveglia/Entella	2	1,1	7	3	5	9	22	2	23	29	100,0	n.d.	n.d.	4	13	70	1	0,6	2	2	21	4	47	7	7	8	3	0	100,0
		0,5	2	1	5	4	10	3	4	8					13	7													
Gromolo/Petronio/Castagnola	3	1,0	5	7	3	3	15	1	28	37	100,0	n.d.	82	n.d.	15	69	2	6,6	0	0	7	4	66	13	2	7	2	0	100,0
		0,4	2	4	3	2	1	1	6	8			5		18	7		0,1	0	0	7	6	36	12	2	9	1	0	
Ghiaiaro	1	1,5	3	5	0	2	37	0	34	19	100,0	n.d.	90	n.d.	0	50													
Vara	2	0,7	18	13	1	10	30	2	11	15	100,0	37	59	0	17	69	1	0,7	1	0	6	0	75	10	2	4	3	0	100,0
		0,3	1	3	1	5	2	1	3	4		15	13		24	16													
BRACCO - beaches																													
Zoagli/Chiavari/Sestri L./Riva T.	4	1,0	18	7	8	11	16	3	13	25	100,0	38	81	0	17	70	2	2,1	0	0	23	10	38	12	3	11	2	0	100,0
		0,7	11	7	4	11	7	2	4	8		15	2	0	23	22		0,5	0	0	6	9	9	3	1	6	2	0	
Moneglia	1	1,5	42	10	0	10	23	1	13	1	100,0	32	67	0	0	n.d.													
Deiva/Fram./Levanto/Bonass./M.rosso	5	0,9	7	27	7	6	11	1	10	31	100,0	51	91	0	39	65	3	8,2	0	0	20	3	65	6	1	3	1	0	100,0
		0,6	6	19	7	4	7	1	3	16		11	9		31	13		3,3	0	0	13	3	22	6	1	1	1	0	

Means and standard deviations are provided for key indexes defining framework composition and transparent heavy mineral suites. Indexes as in Tables 1 and 2. * Data for the Reno River at Comacchio from Gazzi et al. (1973).

Table 4 - Compilation of framework composition and transparent heavy mineral suites for Ligurid, Epiligurid and foredeep synorogenic clastics of Late Cretaceous to Neogene age. Note fairly good correspondence - particularly as regards heavy mineral suites - between the obtained grand mean and key indexes for the mostly recycled Parma/Modena Apennine river sands.

	REF	N	**Q**	**F**	**Lv**	**Lc**	**Lt**	**Lch**	**Lm**	**Lo**	TOT	P/F	REF	N	%HM	**ZTR**	**T&O**	**Hb**	**AA**	**CPX**	**OPX**	**OS**	**LgM**	**Gt**	**HgM**	TOT
FOREDEEP UNITS																										
Marnoso-Arenacea	1	47	51	32	2	7	3	1	3	1	100,0	58	1	47	1,3%	10	3	0	0	0	0	2	7	74	4	100,0
Cervarola	2,6	31	48	32	1	2	1	0	15	0	100,0	45	2	14		28	6	0	0	3	0	0	20	43	0	100,0
Macigno	2	18	53	40	3	0	0	0	4	0	100,0	69	2,3	30	0,6%	12	9	0	0	1	0	0	25	52	0	99,7
EPILIGURID UNITS																										
Bismantova	4	45	50	25	2	8	8	0	5	2	100,0	55	5	5	0,7%	5	6	0	2	0	0	0	32	51	4	100,0
Antognola													5	6	8,8%	3	5	3	7	2	0	0	49	31	0	100,0
Ranzano3	5,6	26	20	8	1	17	4	1	28	22	100,0	42	5	12	1,3%	4	11	6	6	6	0	9	30	27	0	100,2
Ranzano2	5,6	17	25	20	2	8	2	1	20	22	100,0	33	5	39	1,3%	12	5	0	1	0	0	27	22	32	0	100,0
Ranzano1	5,6	15	39	27	1	1	0	0	30	1	100,1	33	5	8	1,3%	7	4	0	0	0	0	1	48	39	1	100,0
Loiano	5	14	56	41	2	0	0	0	1	0	100,1	44	5	19	0,4%	7	3	0	0	0	0	0	1	57	32	100,0
LIGURID UNITS																										
Antola	4	6	58	38	1	0	0	0	4	0	100,0	86	4	3	0,1%	65	31	0	0	0	0	0	1	2	0	100,0
Caio	4	12	43	34	2	3	7	1	7	4	100,0	86	4	12	0,3%	40	6	0	0	0	0	20	0	34	0	100,0
Cassio	4	9	61	22	2	8	2	1	4	0	100,0	52	4	9	0,3%	39	11	0	0	0	0	0	0	40	10	99,9
Solignano	4	25	52	32	5	2	0	0	8	0	100,0	59	4	10	0,2%	28	8	0	0	0	0	0	2	56	6	100,0
Mt. Venere/Monghidoro	2	12	59	38	0	2	0	0	1	0	100,0	50	3	10	0,4%	13	3	0	0	0	0	0	1	56	25	98,6
Gottero	2,7	42	50	38	3	0	0	0	8	0	100,0	25	3	15	0,1%	22	13	0	0	0	0	0	16	48	0	100,0
GRAND MEAN	N =	443	**48**	**31**	**2**	**4**	**2**	**0**	**10**	**4**	100,0	**54**	N =	229	1,2%	**20**	**8**	**1**	**1**	**1**	**0**	**4**	**17**	**43**	**5**	99,9
standard deviation			*12*	*9*	*1*	*5*	*3*	*0*	*10*	*8*		*18*				*18*	*7*	*2*	*2*	*2*	*0*	*8*	*17*	*17*	*10*	
S EMILIA APENNINE	N =	5	57	15	0	4	2	6	8	7	100,0	45	N =	3	2,1%	11	7	8	2	3	2	4	12	46	5	100,0
Parma/Baganza/Enza/Secchia/Panaro			Recalculated arbitrarily setting Lc=4 and Lt=2													*6*	*2*	*5*	*1*	*2*	*2*	*3*	*5*	*1*	*5*	

Key indexes are recalculated from original data contained in references (REF): 1) Gandolfi et al. (1983); 2) Valloni and Zuffa (1984), Mezzadri and Valloni (1981), Vescovi and Valloni (1986), Valloni et al. (1991); 3) Gazzi (1965a,1965b, 1966); 4) Fontana et al. (1992; 1994), Fontana and Spadafora (1994); 5) Cibin (1993), Cibin et al. (1993); 6) Di Giulio (1990), Andreozzi and Di Giulio (1994); 7) Pandolfi, 1996. Sources of informations are not always consistent, particularly as regards the P/F ratio. Heavy minerals for the Gottero Sandstone (after Gazzi, 1965b) include the Gottero and Molinatico sandstones but not the strongly depleted, ZTR-dominated Ramaceto and Zatta sandstones.

Detrital quartz, limestone, terrigenous and metapelitic grains are more abundant in the Bormida sands, largely derived - directly or indirectly through recycling of Piedmont Tertiary Basin clastics - from alpine Brianzonese Units exposed in the upper drainage. Ophiolitic detritus derived from the westernmost limbs of the Voltri Massif is still significant for the Bormida di Spigno, but almost negligible for the Bormida di Millesimo.

Liguria beach and river sands from Cogoleto to Pegli compare closely with that of the Bormida River tributaries (Tab. 3). Fluvial sands are poorer in quartz and richer in metamorphic lithics and serpentineschist lithics (particularly in the Varenna sand; Fig. 3A). Beach sands have a few dolomitic grains (e.g., Cogoleto) derived from nearby Triassic carbonates of the Piemontese Domain (Cogoleto Dolomite). Volcanic grains are very few, but clasts of pillow basalts with branching augite were recorded.

Sand of the Polcevera River - running S-wards along the Sestri/Voltaggio Zone at the eastern margin of the Voltri Massif - compare with that of the Bormida di Spigno - running N-wards at the western margin of the Voltri Massif -, the former containing more terrigenous lithics and less serpentineschist grains.

Along the coast towards Savona (Celle/Varazze area), ophioliticlastic detritus is progressively replaced by detritus derived directly or indirectly - through recycling of the Piedmont Teriary Basin clastics - from the alpine basement of the Brianzonese Domain. The Teiro sand contains an abundance of metamorphic lithics - along with common poikiloblastic albite (Fig. 3B) -, mostly derived from prasinites and calcschists of the Voltri Group but a few also indirectly from alpine basement rocks (e.g., sillimanite gneiss).

Heavy mineral suites

The Bormida Basin sands are dominated by mainly greenschist facies metamorphic minerals (i.e., amphiboles, epidotes); the Orba sand is particularly rich in tremolite and actinolite, including green-bluish amphiboles derived from retrocession of blueschist facies basic rocks of the Voltri Massif. Whereas the Bormida di Millesimo sand contains less pyriboles (mostly hornblende or glaucophane recycled from Piedmont Tertiary Basin clastics), sand carried by tributaries invariably include clino- and orthopyroxenes derived from the Voltri ophiolites.

Liguria beaches and river sands compare with that of Bormida River tributaries, but contain more clinopyroxenes and less epidote. The Arrestra sand is extremely-rich in actinolite (including green-bluish amphiboles). Spinel is invariably very minor.

BRACCO PROVINCE

Framework composition

River and beach sands from Zoagli to Monterosso contain both cellular serpentinite and serpentineschist lithics, with only sporadic serpentinized peridotites including olivine, pyroxene or spinel relics (Fig. 3C). In the eastern part of the province (e.g., Bonassola, Monterosso), occurrence of a few gabbroic rock fragments but particularly great abundance of strongly altered plagioclase in beach sands indicate locally very important contribution from intrusive rocks of the oceanic crust (e.g., Tribuzio et al., 1997). Volcanic lithics (mostly lathwork basaltic grains with few diabase rock fragments; e.g., Riva Trigoso and Framura sands; Fig. 3D) and chert grains (significant only in the western part of the province, from Zoagli to Sestri Levante) document subordinate supply from lavas and oceanic sediments.

A few calcareous grains and invariably common terrigenous rock fragments (mainly pelitic, but including carbonate and quartzo-feldspathic arenite) document erosion of Ligurid flysches. Recycling of mainly Internal Ligurid quartzo-feldspathic turbidites (e.g., Gottero Sandstone), exposed along the coast and in the Vara River drainage, accounts for anomalous quartz abundance in the Moneglia and Sestri Levante beach sands, and for relative abundance of quartz, feldspars and terrigenous lithics in the Vara sand (Fig. 3F). The Macigno foredeep sanstones also provide little amounts of quartz, feldspars and terrigenous lithics to the Ghiaiaro and Vara sands.

Data for the Graveglia, Entella and Chiavari sands are very close with those in McBride and Picard (1987), even though the latter were not collected according to the Gazzi-Dickinson method.

The Lavagna sand upstream from the confluence with the Graveglia River is dominated by shale, slate and phyllite lithics derived from the mildly metamorphosed Cretaceous sedimentary cover of the Internal Ligurids (Fig. 3E). Similar composition displays the Ghiaiaro sand, but with more abundant serpentine grains.

Non durable metamorphic lithics are more abundant in river sands; quartz is locally enriched in beach sands (Tab. 3).

Heavy mineral suites

The Bracco Province is characterized by great abundance of diallage (Bonassola, Castagnola, Vara and Monterosso sands), largely derived from gabbroic rocks. Invariably dominant clinopyroxene is associated with orthopyroxenes and hornblende. Olivine and spinel are very minor. Tremolite is common in the Chiavari sand.

The Lavagna sand is at first mostly derived from Internal Ligurid flysches and characterized by peculiar abundance of zircon and blue anatase, with low diallage. Ophiolitic detritus becomes dominant downstream of the Sturla River confluence, marking a sharp increase in pyroxenes and epidotes, followed by a further increase in diallage downstream of the Graveglia River confluence.

SOURCES OF DETRITUS

The Alps/Apennine boundary represents an ideal area to investigate contrasting petrographical and mineralogical signatures of detritus derived from thick-skinned versus thin-skinned thrust-belts including ophiolitic sequences (i.e., alpine-type and apenninic-type orogens; Doglioni, 1992). Methods adopted and data collected in the present work allow to clearly discriminate among various sources of detritus, including continental basement and cover rocks, carbonatic to siliciclastic synorogenic turbidites, and in particular ophiolitic complexes which have undergone various degrees of orogenic deformation, from high-pressure metamorphism during alpine subduction to incorporation at much shallower levels within the apenninic accretionary prism (Fig. 4; Tab. 5).

Detritus from continental domains

Deformed continental basement rocks and sedimentary cover are exposed only at the southwestern corner of the study area, where Brianzonese or Piemontese Units provide quartz, feldspars, metamorphic and sedimentary rock fragments directly only to the upper reaches of the Bormida River and sporadically to a few Liguria beaches (e.g., Cogoleto), but indirectly - through recycling of Piedmont Tertiary Basin clastics - to a much larger region, including the whole Bormida Basin, the Polcevera, Scrivia, Curone, Staffora rivers and the Celle/Varazze area. Continental basement sources are indicated by excess quartz (typically above 15 in the Voltri Province and up to 44 in the Bormida di Millesimo), high Qp/Q ratios (typically above 50 in the Bormida Basin and Voltri Province and up to 92 and 94 in the Teiro and Lemme sands) and relatively low P/F ratios (typically around 40, even in the ophioliticlastic Orba sand).

Contribution from sedimentary successions deposited on continental crust (e.g., Triassic dolostones) is documented by high Lcd/Lc ratios (typically above 80) in western Liguria beaches. Dolostone grains derived from Piemontese cover rocks are recorded as far east as the Sestri/Voltaggio Zone (Lcd/Lc= 19 in the Polcevera sand). The few dolomitic rock fragments found in apenninic rivers (e.g., Nure sands) are instead most likely derived indirectly from Triassic cover rocks of Adria through recycling of turbidites of Insubric affinity found at the base of the Cassio Unit (e.g., Salti del Diavolo Conglomerate, Ostia-Scabiazza Fms.).

Low-Q polycyclic detritus from the External Ligurid and Epiligurid turbidites

Little quartz, a few feldspars (K-spar slightly more abundant than plagioclase) and metamorphic lithics, garnet and up to high-grade metamorphic heavy minerals found in river to beach sands from the Emilia Apennine to central-eastern Liguria are indirectly derived from continental sources, through recycling of synorogenic turbiditic rocks originally deposited in remnant ocean, thrust-sheet-top or foredeep basins from the Late Cretaceous to the Neogene. Apart from excess quartz and feldspars recorded in a few samples documenting greater contribution from Epiligurid or foredeep units (i.e., Stirone, Secchia, Reno), sands derived from mostly marly-calcareous External Ligurid flysches represent a peculiar example of low-quartz, carbonaticlastic polyciclic sands (Q typically below 15; Lc up to 74 in the Parma and Camogli sands), documenting that mineralogical stability of both framework and heavy mineral grains does not necessarily increase through sediment-recycling processes (e.g., Cavazza et al., 1993) (Tab. 4).

High-Lm detritus from the Internal Ligurid turbidites

The Internal Ligurid flysches - which with respect to the "helminthoid flysch" of the External Ligurids are largely terrigenous and more metamorphic - supply largely shale to slate and phyllite grains (e.g., Lm up to 67 and 71 in the Lavagna sands, with Lmb/Lm only 1 ÷ 2) but also recycled quartzo-feldspathic detritus to most sands of the Bracco Province (e.g., Q up to 33 and 42 in the Sestri Levante and Moneglia beaches).

Heavy mineral suites are characterized by common amphiboles and both clino- and orthopyroxenes, as documented by the Lavagna sand upstream of the confluence with the Sturla River.

Internal Ligurid pelitic turbidites provide shale to phyllite grains – along with amphiboles and pyroxenes - also to the Polcevera River and to the upper reaches of the Antola Province rivers.

High-Lo detritus from apenninic and alpine ophiolites

In all studied samples, detritus from oceanic rocks is mixed with detritus from synorogenic clastic wedges or continental sources. Invariably dominant serpentine lithics with respect to volcanic and chert grains reflects the scarcity of

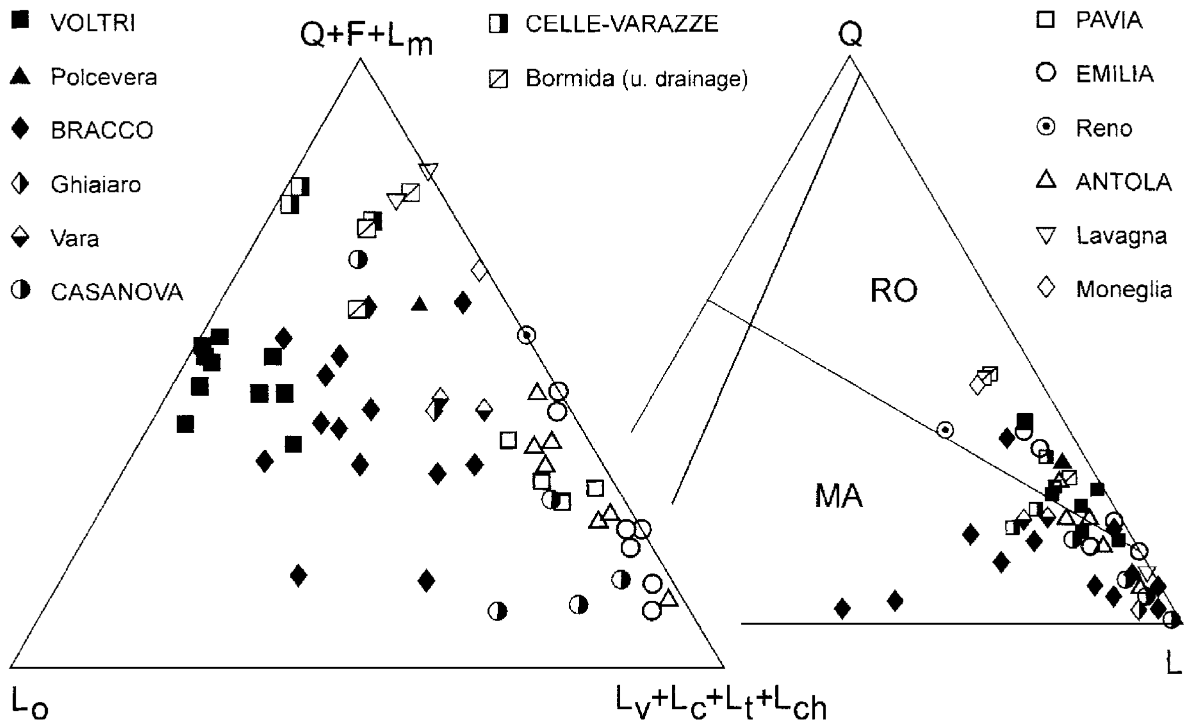

Fig. 4 - Framework composition. The triangular diagram allows distinction of mantle components (Lo index) from crustal/recycled (Q+F+Lm indexes) and cover components (Lv+Lc+Lt+Lch indexes), and effectively discriminates main provinces and various subprovinces of modern sands derived from the Northern Apennines. Standard QFL-type plots are instead inadequate: most samples - but for the quartz-poor and plagioclase-rich gabbroclastic beach sands of the eastern Bracco Province - plot close to the L pole, straddling the boundary between "magmatic arc" (MA) and "recycled orogen" (RO) provenance fields (Dickinson, 1985). The Casanova group includes the Trebbia, Nure, Taro and Sturla sands.

intrusive and effusive crustal rocks in all Liguria ophiolites.

Detritus derived from the External Ligurid peridotites (e.g., Casanova Complex; Lo up to 27 in the Trebbia sand) is overwhelmed by sedimentary or very low-grade metamorphic detritus from the surrounding turbiditic sedimentary rocks (largely External Ligurid "helminthoid flysch" in the Emilia Apennine and Internal Ligurid Cretaceous pelitic rocks in Liguria), but nevertheless dominates the heavy mineral fraction in the Trebbia, Nure, Taro and Lavagna (downstream from the confluence with the Sturla River, which receives detritus from both External and Internal Ligurid ophiolites) sands. Only rivers draining the External Ligurid ophiolites (e.g., Taro, Nure, Trebbia) carry abundant chromian spinel, reflecting greater abundance of mantle peridotites than in the Bracco and Voltri ophiolites.

Detritus derived from the Internal Ligurid ophiolites (i.e., Bracco Unit) include both cellular serpentinite lithics - only locally containing relics of olivine, pyroxene or spinel - and serpentineschists. Mantle-derived grains (Lo up to 52 in the Framura sand) are locally exceeded by detritus from intrusive gabbroic rocks in the eastern part of the Bracco Province (e.g., Bonassola sand), as indicated by great abundance of altered plagioclase and diallage (F up to 50; P/F up to 97; CP up to 91). Subordinate mafic volcanic lithics (Lv up to 17 at Framura) and chert grains (Lch invariably below 5) indicate minor contribution of sea-floor basalts and jaspers mainly in the western part of the Bracco Province.

The alpine ophiolites of the Voltri Massif provide maximum abundance of serpentineschist lithics derived from pervasively deformed mantle rocks, associated with metamorphic lithics and common poikiloblastic albite derived from metamorphosed igneous and pelitic cover rocks (Lo up to 55 and Lm up to 31 in the Varenna sand, with Lmb/Lm= 20, Lmb/Lm reaching 46 in the Orba sand). Serpentineschist lithics are exclusive in central-western Liguria (Loc/Lo= 0); cellular serpentinite lithics are very few in the Bormida basin sands (Loc/Lo= 1 to 6), but increase in the Lemme and Polcevera sands derived from the Sestri/Voltaggo Zone, and in the Genova beach sand (Loc/Lo= 11 to 15).

East of the Sestri/Voltaggio Zone, in the Pavia Apennine, the Loc/Lo ratio increases progressively eastward - away from the Voltri Massif - from the Scrivia to the Curone and Staffora sands (Loc/Lo= 5 to 48).

In the Bracco Province, cellular serpentinite becomes prevalent, but serpentineschist lithics are still common (average Loc/Lo= 68). The Loc/Lo ratio increases further in river sands derived from the External Ligurid ophiolites from south (Loc/Lo= 75 and 85 for the Sturla and Taro sands) to north (Loc/Lo= 88 and 90 in the Nure and Trebbia sands), indicating much lower deformation with respect to other Liguria ophiolites.

This trend, along with consistently higher Lm in Liguria sands with respect to the apenninic tributaries of the Po River, reflects decreasing metamorphic grade from high-pressure metamorphic ophiolitic rocks of the Alpine belt to progressively higher structural levels within the apenninic accretionary prism.

Transparent heavy mineral suites document even more clearly the profoundly different, pyroxene-dominated associations characterizing detritus from the External (clinopyroxenes, orthopyroxenes, spinel) and Internal Ligurid ophiolites (dominant diallage) from associations derived from the alpine metamorphic Voltri ophiolites, which are characterized by amphiboles (e.g., tremolite, actinolite, glaucophane) grown both at high-pressure metamorphic conditions developed during alpine oceanic subduction and due to subsequent retrocession in greenschist facies during alpine exhumation (Fig. 5).

Table 5 - Major provenances, provinces, sub-provinces and variants (e.g., river vs. beach sand) recognized in Liguria and the Northern Apennines.

PROVINCES	N	grain size	Q	F	Lv	Lc	Lt	Lch	Lm	Lo	TOTAL	Qp/Q	P/F	Lcd/Lc	Lmb/Lm	Loc/Lo	N	HM%FS	ZTR	T&O	Hb	AA	CPX	OPX	OS	LgM	Gt	HgM	TOTAL
CARBONATICLASTIC SANDS FROM FLYSCH SOURCES																													
APENNINIC PROVINCE - External Ligurid & satellite basin clastics with sparse peridotites																													
PAVIA APENNINE	4	1,5	19	6	0	45	15	0	6	8	100,0	35	43	0	8	28	4	5,7	4	13	8	9	1	1	1	14	47	3	100,0
		0,4	4	1	0	8	7	0	2	4		6	4	1	0	22		1,4	2	5	3	2	1	0	2	4	5	1	
PIACENZA APENNINE	2	1,5	4	1	3	51	14	1	5	21	100,0	n.d.	n.d.	5	n.d.	89	2	4,2	3	2	5	2	35	13	15	15	8	3	100,0
		0,3	4	0	1	8	2	2	4	9				2		1		1,1	2	0	4	1	1	13	6	9	8	2	
EMILIA APENNINE	10	2,0	16	5	1	54	17	1	2	4	100,0	33	45	0	n.d.	85	4	1,7	10	7	7	2	4	3	11	12	39	4	100,0
		0,6	9	3	2	11	7	2	2	3		14	0	1				1,3	6	2	4	1	4	2	13	4	13	4	
ANTOLA PROVINCE - Antola Unit ("helminthoid flysch")																													
ANTOLA - rivers	3	0,9	17	4	1	42	17	0	15	4	100,0	66	60	2	3	n.d.	1	3,1	2	3	25	9	6	2	1	20	32	3	100,0
		0,2	4	3	2	9	3	0	5	1		7		2	2														
ANTOLA - beaches	5	0,9	17	5	2	52	13	1	5	5	100,0	46	57	2	n.d.	15	2	1,5	1	2	22	18	12	15	3	11	15	1	100,0
		0,6	6	2	3	20	8	2	2	3		1	5	2				1,3	1	1	2	12	4	6	1	0	15	0	
OPHIOLITICLASTIC SANDS FROM OPHIOLITIC SOURCES																													
VOLTRI PROVINCE - Alpine metamorphic ophiolites																													
BORMIDA - l. drainage & right tributaries	4	0,5	24	5	1	2	2	1	20	45	100,0	69	41	0	36	4	3	9,6	1	4	12	30	8	9	1	25	10	1	100,0
		0,4	8	3	1	2	3	2	5	5		22	1		11	5		2,6	0	3	3	5	1	4	1	5	6	2	
VOLTRI - rivers	3	1,1	13	6	0	2	1	0	29	49	100,0	64	57	n.d.	24	0	2	22	1	2	7	37	23	11	0	14	5	0	100,0
		0,2	7	2	0	1	1	0	2	5		9	4		5	0		18	0	1	1	21	16	5	0	2	2	0	
VOLTRI - beaches	3	1,2	20	5	0	11	3	1	19	40	100,0	58	80	81	20	0	2	16	2	3	15	21	14	11	2	17	16	1	100,0
		0,2	4	3	0	6	2	1	6	3		8	0	21	15	0		14	1	1	4	4	2	6	2	2	2	0	
BRACCO PROVINCE - Internal Ligurid ophiolites																													
BRACCO - rivers	5	1,0	6	5	4	5	18	2	26	34	100,0	n.d.	82	4	14	69	2	6,6	0	0	7	4	66	13	2	7	2	0	100,0
		0,4	2	4	4	4	6	2	6	8			5		14	6		0,1	0	0	7	6	36	12	2	9	1	0	
BRACCO - beaches	9	1,0	12	18	8	8	13	2	11	28	100,0	43	87	0	29	68	3	2,1	0	0	20	3	65	6	1	3	1	0	100,0
		0,7	10	18	6	8	7	2	4	13		14	9	0	28	17		0,5	0	0	13	3	22	6	1	1	1	0	
METAMORPHICLASTIC-SEDIMENTICLASTIC-OPHIOLITICLASTIC SANDS FROM OCEANIC APENNINIC SOURCES																													
BRACCO PROVINCE - Internal Ligurid flysches & ophiolites																													
Lavagna/Sturla	3	1,7	10	1	2	3	12	1	63	8	100,0	47	n.d.	n.d.	2	75	2	0,3	10	7	10	9	24	14	2	14	12	0	100,0
		0,7	2	0	2	0	3	1	10	9					1	0		0,1	9	6	6	9	21	4	2	7	5	0	
Ghiaiaro	1	1,5	3	5	0	2	37	0	34	19	100,0	n.d.	90	n.d.	0	50													
Vara	2	0,7	18	13	1	10	30	2	11	15	100,0	37	59	0	17	69	1	0,7	1	0	6	0	75	10	2	4	3	0	100,0
		0,3	1	3	1	5	2	1	3	4		15	13	0	24	16													
Moneglia	1	2	42	10	0	10	23	1	13	1	100,0	32	67	0	0	n.d.													
METAMORPHICLASTIC-OPHIOLITICLASTIC SANDS FROM CONTINENTAL AND OCEANIC ALPINE SOURCES																													
PERIPHERY OF VOLTRI PROVINCE - Metamorphic alpine basements & Piedmont Tertiary Basin clastics																													
BORMIDA - upper drainage	3	1,5	38	6	0	11	7	0	25	13	100,0	60	33	0	16	5	1	3,7	11	2	21	16	1	2	0	31	15	3	100,0
		0,6	10	2	0	1	1	0	4	9		9	19	0	10	1													
CELLE/VARAZZE - rivers	1	0,9	17	17	0	1	0	1	45	19	100,0	92	89	n.d.	43	n.d.													
CELLE/VARAZZE - beaches	2	1,0	25	9	0	7	1	0	40	17	100,0	81	95	85	21	0													
		0,0	7	4	0	8	1	0	5	7		15			7	0													
Polcevera	1	1,2	28	4	1	13	15	0	27	12	100,0	66	n.d.	19	10	15	1	0,6	1	3	9	17	29	7	5	11	19	1	100,0

Means and standard deviations are provided for key indexes defining framework composition and transparent heavy mineral suites (see text for full explanation). The Reno river sand is not considered.

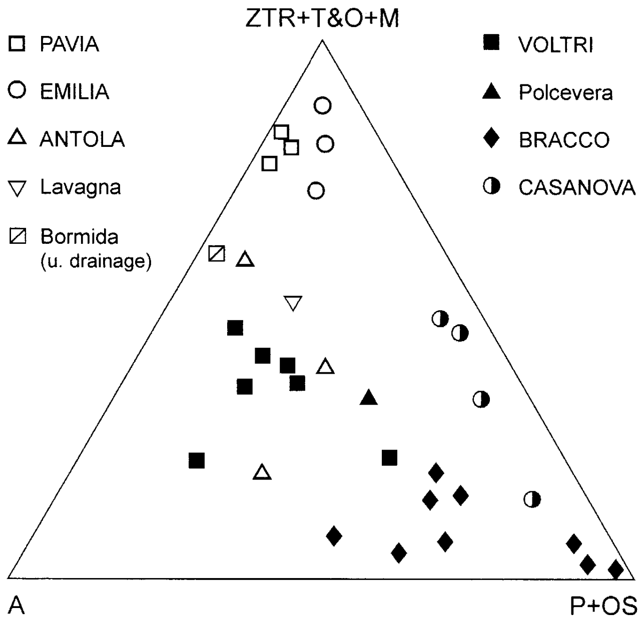

Fig. 5 - Transparent heavy mineral suites. The triangular diagram effectively discriminates between amphibole-rich sands derived from blueschist to greenschist metamorphic alpine ophiolites (Voltri Province), pyroxene-rich sands derived from Internal Ligurid ophiolites (Bracco Province), and pyroxene- to spinel-rich sands derived from mainly External Ligurid peridotites and turbidites (Casanova group, including the Trebbia, Nure, Taro and Lavagna/Sturla sands). Garnet-rich sands of the Apenninic Province can also be distinguished according to their content in pyriboles: mostly amphiboles derived directly or indirectly from alpine ophiolites (Pavia Apennine) versus a few pyroxenes and spinels derived from External Ligurid peridotites (Emilia Apennine). The Antola Province samples, as well as the Bormida, Polcevera and Lavagna sands, plot around the Voltri Province samples, indicating direct or indirect contributions from ophiolitic sources. A= total amphiboles (Hb+AA); P= total pyroxenes (CPX+OPX); M= metamorphic minerals (LgM+Gt+HgM); other indexes explained in text. Such diagrams can help differentiating suture belts with contrasting vergence and deformational style in studies of ancient clastic suites.

Heavy mineral concentrations

Ophiolitic sources invariably produce conspicuous quantities of heavy minerals. Peak values are reached in the Voltri Province (up to 26% and 34% of the very fine to fine sand fraction), derived from alpine ophiolites. Consistently high values are obtained also for the eastern part of the Bracco Province (mostly 5 to 10%). Even the External Ligurid ophiolites (representing only about 1% in the Taro basin to 4% in the Trebbia basin; Tab. 6) provide to the Taro, Nure and Trebbia sands more heavy minerals than the much more extensive turbiditic rocks.

Recycling of synorogenic turbidites of both External and Internal Ligurid units in fact invariably produces detritus with low percentages of heavy minerals (e.g., Emilia Apennine river sands; sands in the Antola Province to westernmost part of the Bracco Province; Vara sand). The heavy mineral fraction increases only in the Pavia Apennine (6% to 7% in the Scrivia, Curone and Staffora sands).

Values for mothern sands are one order of magnitude greater than those for ancient sandstones, pointing to the importance of intrastratal solution phenomena in the latter (e.g., Morton, 1985).

River vs. beach sands

Framework petrography and heavy mineral suites of river and beach sands can be compared for four provinces and sub-provinces of the Liguria coast (i.e., Bracco, Antola, Voltri, Celle/Varazze; Tab. 5) with two principal aims: a) evaluate compositional modifications in high-energy nearshore environments; b) test the effect of periodic re-nourishments.

Metamorphic rock fragments are invariably depleted in beach sands, and thus appear to be by far the least durable grains (e.g., Cameron and Blatt, 1971; Garzanti et al., 1998), which are rapidly and selectively destroyed by wave action in marine settings (McBride and Picard, 1987). Fine-grained foliated metamorphic detritus in general (including serpentineschist lithics and possibly even polycrystalline quartz with respect to monocrystalline quartz) appears to be liable to mecanical abrasion.

Detrital quartz instead tends to be enriched in beach sand; plagioclase is markedly concentrated in beach sands of the eastern Bracco Province largely fed from altered gabbroic rocks. Carbonate rock fragments preferentially occur in beach sands of the western Riviera, but because carbonate rocks (i.e., Cogoleto Dolomite) or conglomerates yielding carbonate clasts (Celle area) are exposed mainly along the coast.

Heavy mineral suites do not show significant differences between river and beach sands. Grains of anthropic origin are invariably rare (average content 0.3% for both river and beach sand).

Good overall correspondence between Liguria river and beach sands, as regards both framework and heavy mineral grains, on one side reflects short residence time of detritus on the narrow continental shelf, and on the other side argues against major effects due to artificial re-nourishments of the Liguria beaches.

CONCLUSIONS

Composition of modern river and beach sands derived from the Northern Apennines faithfully reflects tectonic structure and geologic history of the growing mountain belt. Quantitative analysis of framework composition and heavy mineral suites allows to primarily distinguish carbonaticlastic garnet-rich sands fed through recycling of synorogenic turbidites deposited in remnant-ocean to thrust-sheet-top basin settings (Apenninic and Antola Provinces), from ophioliticlastic pyribole-rich sands fed by erosion of alpine or apenninic ophiolites (Voltri and Bracco Provinces). The major geological boundary marked by the Sestri-Voltaggio Zone corresponds to a sharp boundary between petrographic provinces of modern sand, separating alpine from apenninic provenances.

Sands derived from alpine ophiolites of the Voltri massif (Voltri Province) are dominated by serpentineschist lithics but also contain abundant metabasite, metapelite and metafelsite grains, while amphiboles (tremolite, actinolite, hornblende, glaucophane) prevail over pyroxenes, reflecting provenance from mantle to oceanic cover rocks with extensive blueschist to greenschist-facies metamorphic overprint.

Sands derived from the much less pervasively-deformed Internal Ligurid ophiolites of the Bracco Unit (Bracco Province) are characterized by cellular serpentinite to serpentineschist lithics and very low-grade metapelite grains

Table 6 - Sources of detritus for the various sub-provinces recognized.

SOURCES	PAVIA APENNINE	PIACENZA APENNINE	EMILIA APENNINE	Reno	ANTOLA	Bormida - right tributaries	VOLTRI	Polcevera	Bormida - upper drainage	BRACCO	Lavagna	Vara
Piedmont Tertiary Basin and Epiligurids	24%	1%	14%	23%	1%	35%	0%	0%	73%	----	----	0%
Foredeep units	----	2%	9%	29%	----	----	----	----	----	2%	----	3%
External Ligurid "helminthoid flysches"	74%	75%	58%	14%	63%	3%	----	6%	----	----	1%	----
"Basal complexes" and Subligurid units	2%	18%	18%	34%	----	----	----	----	----	----	----	7%
External Ligurid peridotites	0%	4%	0%	0%	----	----	----	1%	----	----	5%	3%
Internal Ligurid terrigenous flysches	----	0%	1%	----	35%	----	----	83%	----	32%	94%	42%
Internal Ligurid pelagic cover units	----	----	----	----	----	----	----	----	----	29%	0%	9%
Internal Ligurid ophiolites (Bracco Unit)	----	----	----	----	----	----	----	----	----	37%	0%	29%
Calcschists	----	----	----	----	----	7%	45%	2%	0%	----	----	----
Metamorphic ophiolites (Voltri Massif)	----	----	----	----	----	55%	55%	3%	4%	----	----	----
Continental cover units	----	----	----	----	----	0%	0%	4%	4%	----	----	6%
Continental basement units	----	----	----	----	----	0%	0%	0%	19%	----	----	----
TOTAL	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%

Note: a) scarcity of mantle peridotites in drainage basins of apenninic tributaries of the Po River (even in the Piacenza Apennine); b) relative abundance of Epiligurid and foredeep turbidites in the Reno basin; c) dominance of mantle rocks in the Voltri Massif drainage area; d) presence of both mantle and oceanic cover rocks in the Bracco drainage area; e) abundance of Internal Ligurid terrigenous flysch in the Lavagna, Polcevera and Vara basins. Percent areas calculated mainly after Consiglio Nazionale delle Ricerche (1990).

particularly in river sands; locally abundant plagioclase and predominance of diallage among the heavy minerals indicate major contribution - particularly in the eastern part of the Bracco Province - from gabbroic rocks of the oceanic crust. Only locally common lathwork rock fragments and sporadic chert point to limited supply from basalts and overlying pelagic sediments.

Sands derived from detached ophiolitic masses of the External Ligurids yield cellular serpentinite grains but little serpentineschists and metamorphic rock fragments, and contain abundant spinel and pyroxenes, relecting supply from unmetamorphosed fertile peridotites.

Consistently higher metamorphic detritus in Liguria sands (e.g, serpentineschist and metapelite grains) with respect to the apenninic tributaries of the Po River reflects decreasing metamorphic grade from subducted continental and oceanic rocks of the Alpine belt to progressively higher structural levels within the apenninic accretionary prism.

Sands derived from synorogenic Ligurid or Epiligurid wedges (Apenninic and Antola Provinces) represent a peculiar case of low-quartz, carbonaticlastic polycyclic sands, characterized by predominant sedimentary rock fragments. Transparent heavy mineral suites display typically alpine character (predominant garnet and metamorphic minerals), being largely recycled from turbidites in turn derived from the Alps in the successive Cretaceous to Neogene stages of their evolution. This case history thus shows that stability of both framework and heavy mineral grains does not necessarily increase through successive sedimentary cycles. On the contrary, studied samples commonly display less quartz and less ultrastable heavy minerals than their clastic sources.

The good match between composition of Liguria river and beach sands indicates that artificial re-nourishments is luckily not sufficiently extensive to invalidate mineralogical studies of modern sediments.

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