Composition and provenance of the rudite and arenite facies in a foreland basin, northern Marchean Apennines, Italy

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ABSTRACT

The Montecalvo in Foglia basin (Northern Marche, Italy) is infilled by rudite and arenite deposits. The rudite facies (conglomerates) are mainly represented by carbonate, chert, and sandstone clasts while the arenite facies is characterized by a quartzolithic or fedspathic litharenite petrofacies (mean values: Q_{47}, F_{18}, L_{35}). This is characterized by a large number of lithic fragments reflecting a local provenance from the sedimentary cover of the Marchean Apennines.

Morphometric and compositional analyses suggest that the rudites, mostly made up of pebble-to-cobble-sized clasts, derived from the erosion of the «Ligurid» sequences to the northwest of the basin. They were elaborated in fluvio-torrential systems under temperate-warm climate conditions. Afterwards, during relative sea level lowstands, these were eroded, cannibalized and resedimented into fans or aprons confined to the narrow sub-basins of the Adriatic Foredeep.

Textural data of the arenites show a premature diagenesis, characterized by a rapid formation of carbonate cement, which inhibited the mechanical compaction of sediments.

Key words: Northern Marchean Apennines, Pliocene basin, cannibalized fan delta deposits, rudite and arenite composition, provenance, paleogeography.

RESUMEN

El relleno de la cuenca pliocena de Montecalvo in Foglia (Marche septentrional, Italia) se realizó por depósitos rudíticos y areníticos. Las facies rudíticas (conglomerados) están formadas por clastos calcáreos, pedernalinos (cuarcitícos), y de areniscas mientras que las facies areníticas (areniscas) están constituidas por una sola petrofacies: cuarzolítica o litareniscas feldespáticas (Q_{47}, F_{18}, L_{35}).

El estudio morfométrico y el análisis de la composición del sedimento revela que la génesis de estos depósitos está relacionada con el desmantelamiento de las áreas madres del Apenino marchigiano por sistemas fluvio-torrenciales bajo los efectos de un clima cálido templado y que posteriormente, fueron erosionados y canibalizados en los estadios de bajada relativa del nivel del mar e incorporados a la cuenca sedimentaria marina. Por otro lado, el análisis sedimentológico realizado al microscopio revela la existencia de una diagénesis temprana que inhibió los efectos de la compactación del sedimento.

Palabras clave: Apenino, Marche septentrional, cuenca Pliocena, depósitos de fan delta canibalizados, composición de ruditas y arenitas, procedencia, paleogeografía.

INTRODUCTION

The Montecalvo in Foglia basin (MCF) belongs to a foreland basin system or foredeep. It is located on the Apennine margin (Marche region, Italy) and shows an asymmetric structure due to piggyback thrusting; Fig. 1). It is originated and evolved during the compressive tectonic phases from Late Miocene to Early Pliocene (Synorogenic molasse stage of Ricci Lucchi, 1986). It is filled with allochthonous chaotic units (Liguride Complex) and Pliocene marine sediments. In this basin the upper stratigraphic sequence, 142 m thick, is characterized by eight coarse-grained bodies; Figs. 2 and 3). interbedded with hemipelagic mudstones (Capuano *et al.*, 1989).

The interpretation of the depositional processes and environment could have implication for the gravitative transport mechanism of the Ligurid thrust-pile. In fact, the northern part of the basin is occupied by allochthonous units of the Ligurids, consisting of Jurassic to Miocene sediments (Capuano, Tonelli & Veneri, 1987; Capuano, 1990a).

The purpose of this paper is to outline, through morphometric and modal analyses of arenite and rudite facies, the relationships between composition, provenance and paleogeography.

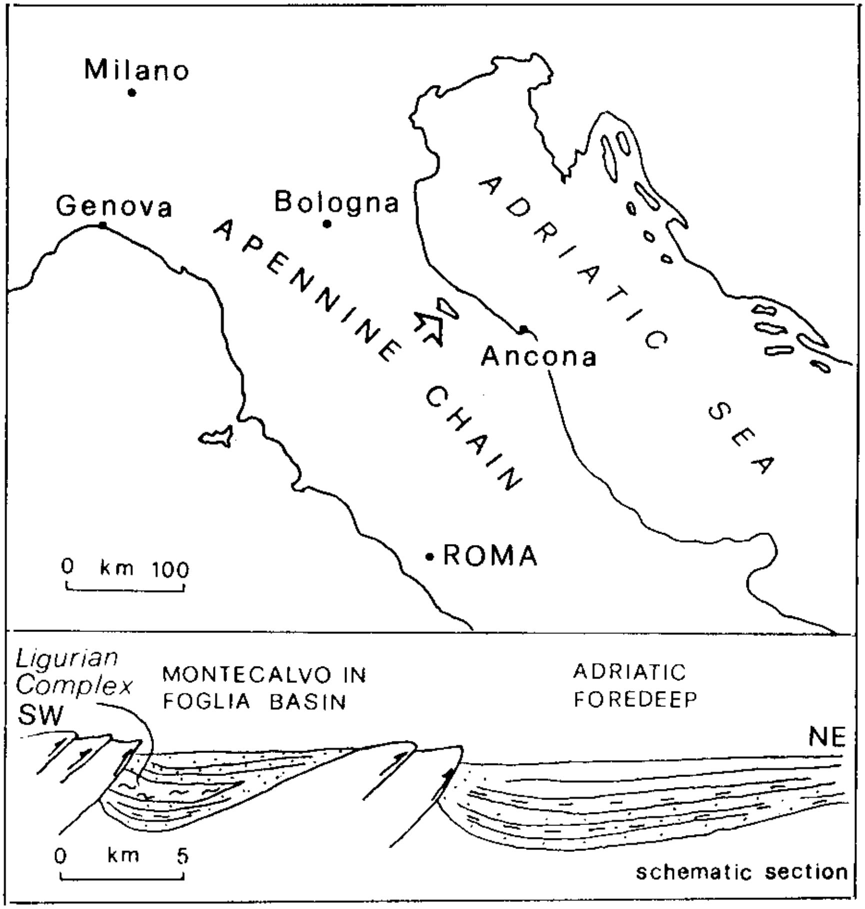


Fig. 1.—Location of the investigated area which shows piggyback thrust basin of Montecalvo in Foglia (MCF).

Fig. 1.— Situación del área investigada que muestra la cuenca a cuestas de Montecalvo en Foglia (MCF).

GRAIN SIZE, MORPHOMETRY AND LITHOLOGY OF THE RUDITES

Rudite facies in the MCF basin are represented by mainly massive disorga-nized clast-supported conglomerates with an arenitic matrix (Fig. 4). Some-times, inverse-to-normal grading occurs within the basal parts of the rudite beds; the arenite portions may display vague horizontal laminations (Fig. 5). These rudites facies are intercalated within bodies 2, 4, 5 and 6, outcropping at the western basin-margin (proximal area; Fig. 3). Most coarse material accumulated at entry point located near Mount Osteriaccia

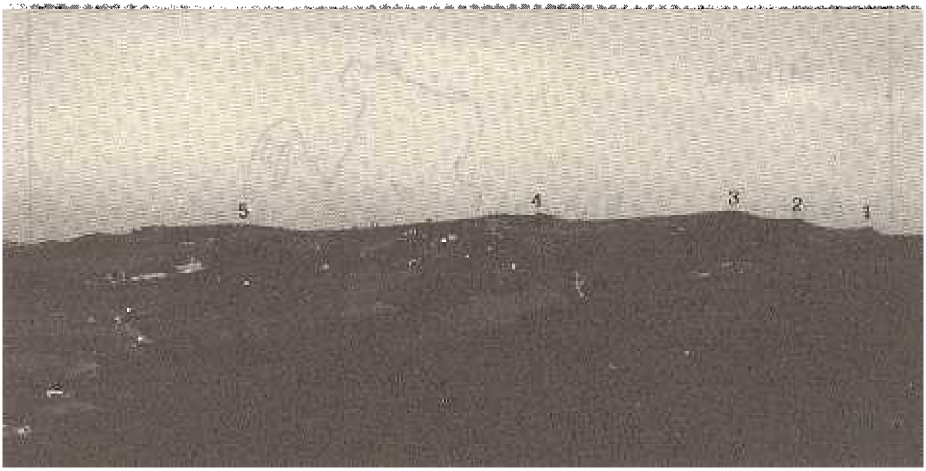


Fig. 2.—General view of the northeastern flank of the MCF basin. Morphological steps of sedimentary bodies No. 1 - 5 are shown.

Fig. 2.—Vista general del flanco noreste de la cuenca MCF. Se han indicado los escalones morfológicos de los cuerpos sedimentarios nº 1 a 5.

(Fig. 3). Sampling of large gravel populations has been carried out to establish its grain-size parameters and form-evolution. In each gravel body pebble-to-cobble-sized clasts are identified. In this area the rudites are distributed and statistically divided into five grain-size classes: 4-8 (1.4 %), 8-16 (16.2 %), 16-32 (46.9 %), 32-64 (32.7 %), 64-128 (2.8 %) mm. Their degree of roundness and form evolution have been determined by using the Cailleux & Tricart (1963) scheme.

Morphometric parameters (flatness, bluntness, dissymmetry, sphericity, roundness and oblate-prolate indexes) have been used following procedures proposed by Cailleux (1945; 1947) and Dobkins & Folk (1970). In the parameter evaluation only the classes 8-16, 16-32, 32-64, 64-128 mm have been consi-dered because of the intrinsic difficulties in precise measurements on small-sized clasts. In order to obtain a maximum accuracy, data has only been gathered for the prevaling carbonate clasts. Texture and shape are also interpreted accordind to Potter (1978), Folk (1980), Mazzullo & Ehrlich (1983) and Ineson (1989).

Analytical results and discussion

Lithologically speaking, the rudites have a variable composition, with clastic elements consisting mainly of carbonate rocks (64 %), chert fragments (30.4 %), and lithic arenites (5.6 %). The carbonate rock clasts, consisting of micrites, biomicrites, marlstones and calcarenites, are mainly derived from the *Alberese*

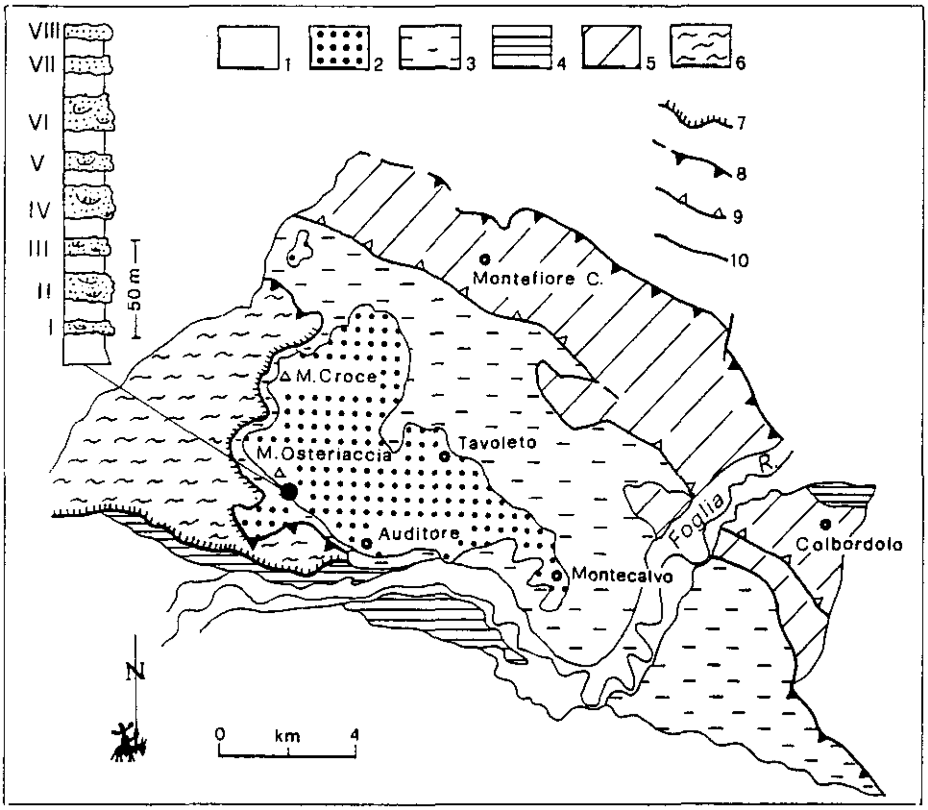


Fig. 3.—Sketch geological map of MCF basin with generalised stratigraphy 1), Terraced alluvial sediments (Holocene); 2), conglomerates and sandstones (Early Pliocene); 3), pelites and thin sandstones (Early Pliocene); 4), Marls (Early Pliocene); 5), Messinian deposits; 6), allochthonous Montefeltro sheet (Ligurids); 7), contact between Umbro-Marchean sequences and allochthonous Montefeltro sheet; 8), thrust; 9), backthrust; 10), faults.

Fig. 3.—Mapa geológico esquemático de la cuenca MCF con la estratigrafía general. (1), terrazas aluviales (Holoceno); (2), conglomerados y areniscas (Plioceno Inferior); (3), lutitas y areniscas delgadas (Plioceno Inferior); (4), margas (Plioceno Inferior); (5), depósitos messinienses; (6), manto alóctono de Montefeltro (Ligurides); (7), contacto entre las secuencias Umbro-Marcheanas y el manto alóctono de Montefeltro; (8), cabalgamiento; (9), retrocabalgamiento; (10), fallas.

and *S.Marino* Formations (Ligurids). The chert granules were derived both from *ophiolite* olistoliths (Ligurids) and from the *Bisciaro* Formation (Miocene umbro-marchean sequence). The lithic arenites, mostly greywacke lithic clasts, were derived both from the *Marnoso-Arenacea* Formation (miocenic terrigenous turbiditic sequence) and the *Pietraforte* Formation (Ligurids). The clastic composition of the arenites (matrix component) and of the rudites is comparable, with minor differences caused by grain size variations.

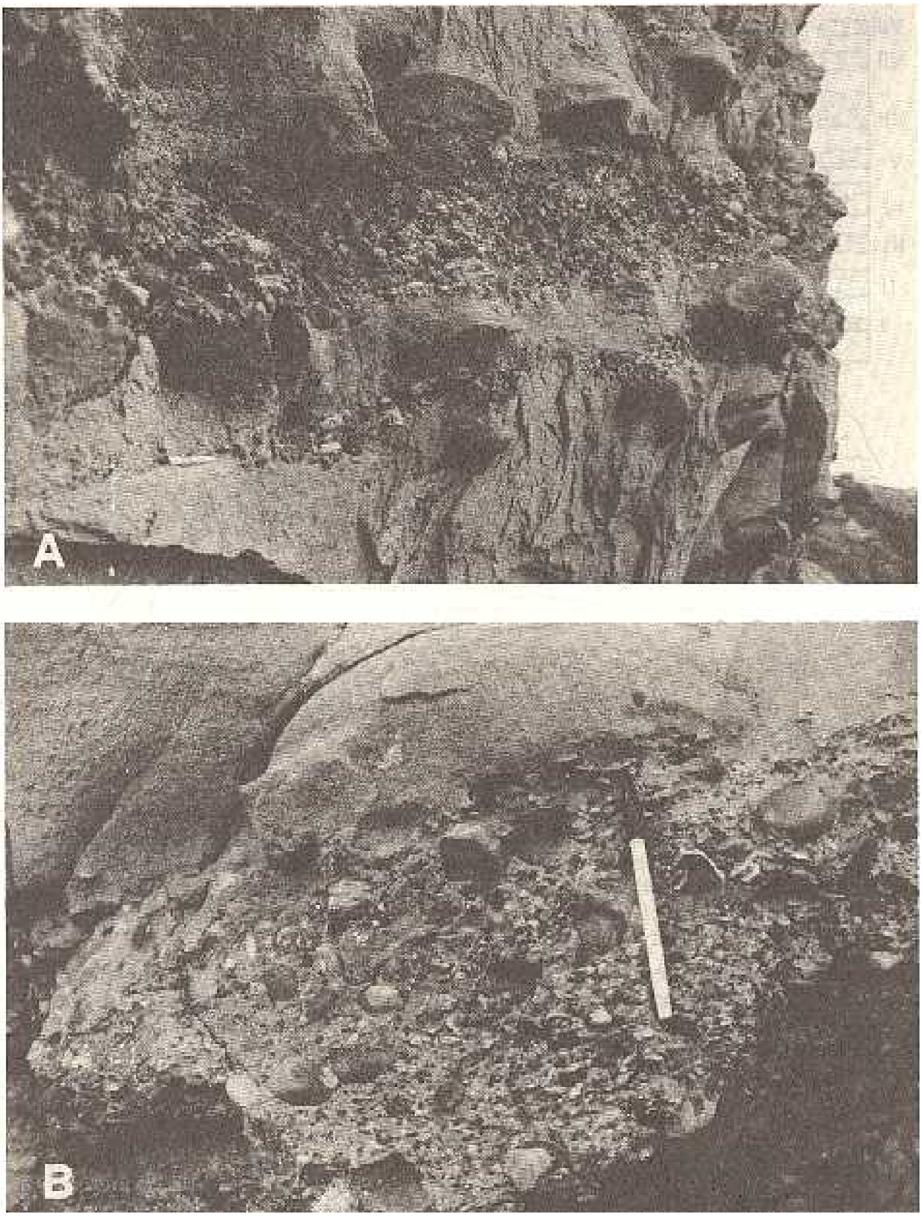


Fig. 4.—Rudite facies interbedded with massive arenite facies (A); note the well-rounded pebbles supported by arenitic matrix with ostreids (B). Il Castellaccio near M.Osteriaccia.

Fig. 4.—Facies de ruditas interestratificadas con facies de arenitas masivas (A); obsérvese los cantos bien redondeados sostenidos por la matriz arenosa con ostreidos (B). Il Castellaccio, cerca de M. Osteriaccia.

Fig. 5.—Clast-supported rudite composed of well-rounded carbonate pebbles. Note inverse-to-normal grading. Il Castellaccio near M.Osteriaccia.

Fig. 5.—Rudita soportada por los clastos constituida por clastos de carbonato redondeados y bien seleccionados. Nótese la granoselección inversa a normal. Il Castellaccio cerca de M. Osteriaccia.

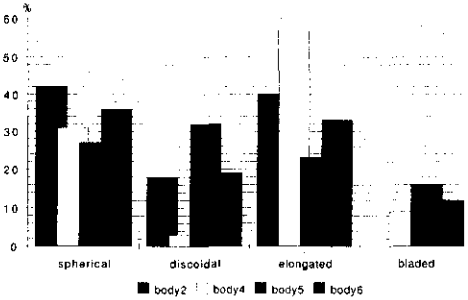


Fig. 6.—Histogram showing the clast-shape distribution in percentage (after Zingg, 1935 modified). The different clast-shape populations reflect specific transport and environmentconditions: at first a fluvial environment, later with residence time in a shallow-marine (i.e. shelf-type fan delta), later on turbulent flow mechanisms in submarine fans (cf. see figure 12).

Fig. 6.—Histograma que muestra la distribución porcentual de morfologías de clastos (según Zingg, 1935 modificado). Las distintas poblaciones reflejan condiciones específicas ambientales y de transporte: al princípio, un ambiente fluvial, luego un tiempo de residencia en ambiente marino somero (es decir, un fan delta de tipo plataforma), más tarde en mecanismos de flujo turbulento en abanicos submarinos (cf. figura 12).

Table 1 shows that flatness mean values decrease as clast-sizes increase. Similarly, bluntness index decreases as clast-sizes increase. Conversly, dissymmetry index gets higher and higher as clast-size increases. Most dissymmetry indexes are not compatible with a beach environment (Cailleux, 1947). Sphericity index is higher in the classes 16-32, 32-64 mm. Roundness indexes, instead, get lower and lower as pebble size increases. Oblate-Prolate indexes are all positive and thus indicative of rod-shapes. Small-sized clasts tend to display bladed shapes, according to the flatness index. The histogram of Fig. 6 mainly evidences spherical (rounded) and elongated (sub-rounded) shapes, while discoidal and bladed shapes are less frequent.

Table 1.—Textural aspects of the rudites of the MCF basin.
Tabla 1.— Aspectos texturales de las ruditas de la cuenca MCF.

			CAILLEUX'S INDEXES			DOBKINS AND FOLK'S INDEXES		
Gravel body number	Grain-size classes mm	Lithology	Flatness	Bluntness	Dissymmetry	Spehericity	Roundness	Oblate-Prolate
2,5,6	8-16	carbonate	1,79	260	510	0,63		1,9
2,4,5,6	16-32	carbonate	1,76	256	550	0,72	0,40	2,7
2,4,5,6	32-64	carbonate	1,60	240	610	0,72	0,39	3,2
2,4,6	64-128	carbonate	1,56	230	640	0,68	0,32	4,5

Processing environment and provenance

The above discussed morphometric data and the prevalence of rounded and sub-rounded shapes are indicative of a fluviatile environment. Pebble populations of class 16-32 mm, indeed, are characterized by a higher degree of sphericity with respect to those belonging to other dimensional classes. This fact depends on gradual shape variation due to different transport modes, i.e. saltation and/or rolling. Conversely, pebbles of class 8-16 mm assume mostly elongated shapes, most likely to be connected to the fragmentation of large clasts. Moreover, pebbles belonging to class 64-128 mm show irregular surfaces and impact shock. We hypothesize that these cobbles underwent short transport and progressive abrasion because of reciprocal impacts, i.e. complex current and/or gravitational interaction. The above discussed data are indicative of a fluvio-torrential system. The same conclusion is achieved with reference to Cailleux & Tricart (1963). In Fig. 7, it may be noted that the analysed rudite samples are included within a superposition area pertaining to different processing environments. Excluding glacial-morenic environments, due to absence of their morphologic features, the pebble-to-cobble samples belong to a fluviatile environment of a warm-temperate, semiarid climate.

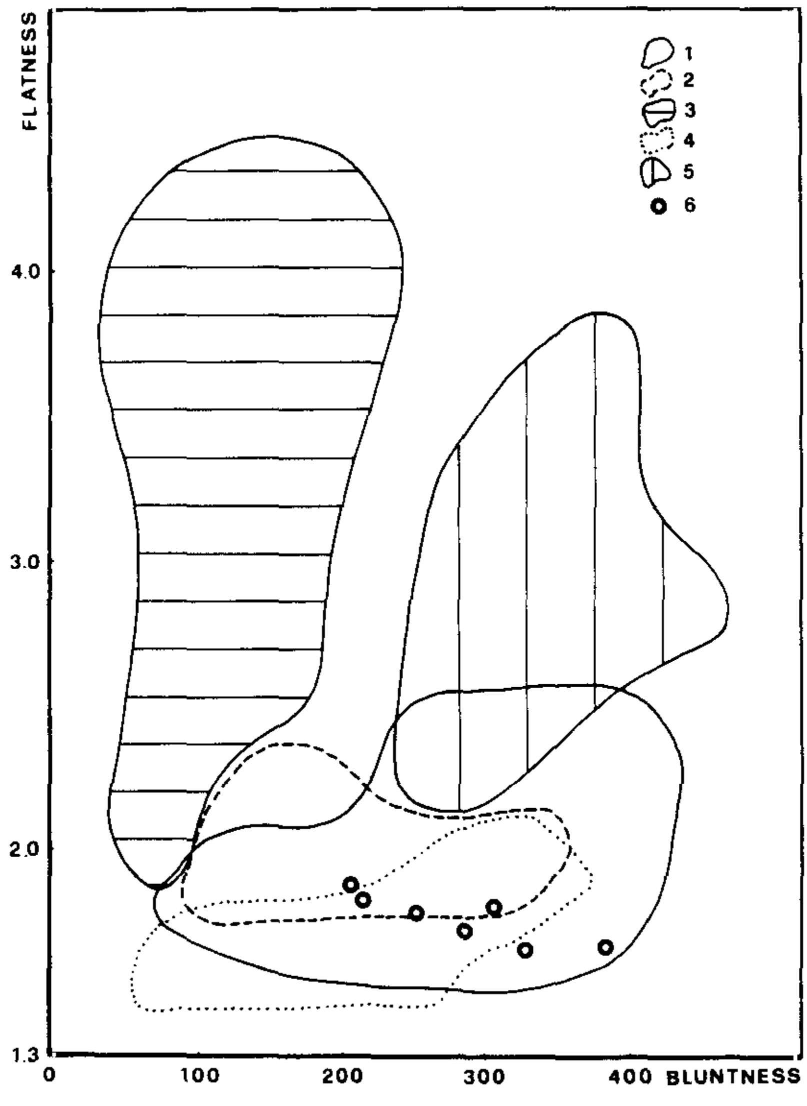


Fig. 7.—Reconstruction of the environment processes of the rudites of MCF comparables with data (scheme) of Cailleux & Tricart (1963) and Dobkins & Folk (1970). 1), Fluviatile temperate-warm; 2), fluviatile in semiarid climate; 3), fluviatile in cold climate; 4), glacial-morenic; 5), marine and lacustrine beach; 6), pebble-to-cobbles analysed, i.e. only carbonate clasts which have a long axis (a) of about 50 mm.

Fig. 7.—Reconstrucción de los procesos ambientales de las ruditas de la MCF comparables con datos (esquema) de Cailleux y Tricart (1963) y de Dobkins y Folk (1970). 1), Fluvial templado-cálido; 2), fluvial en clima semiárido; 3), fluvial en clima frio; 4), glacial-morrénico; 5), playa marina y lacustre; 6), analizadas de cantos a bloques, i.e. sólo los clastos carbonatados cuyo eje mayor (a) mide unos 50 mm.

From a compositional point of view, the rudites derive both from «Ligurid» sequences erosion (located just southwest of the studied basin) and from Miocene sediments (mainly from *Marnoso-Arenacea* Formation).

Sedimentological and biostratigraphical data and the studied rudites seem to be re-deposited in a submarine fan by means of high energy mass-flows (Massari, 1984; Postma, 1984; Ineson, 1989; Capuano, 1990b; Chough, Hwang & Choe, 1990). These gravitative processes may have occurred in very short time spans. This permitted the pebbles-to-cobbles to preserve the morphometric features acquired during the fluviatile elaboration until they were laid down in the marine environment through progradation of a primary deltaic complex (Capuano *et al.*, 1989) or braided-delta distributaries.

PETROGRAPHIC OPTICAL ANALYSES OF THE ARENITES

Due to the absence of appropriate literature, which contrasts with the increasing meaning of this kind of studies in clastic sedimentation basin analyses, I thought it was of primary importance to undertake a petrographic analysis of the collected sandstones. 27 arenaceous samples belonging to seven mapped bodies have been studied, the eighth body having no significant outcrops permitting petrographic analyses.

Procedures

Twenty-seven thin sections were used for textural and compositional analysis. In order to minimize the variation of composition with grain size, point counts were performed following the procedures proposed independently by Gazzi (1966) and Dickinson (1970), and discussed by Gazzi *et al.*, (1973), Ingersoll *et al.*, (1984) and Zuffa (1985). Sandstone point-count data were then recalculated to produce the grain parameters depicted in plot diagrams

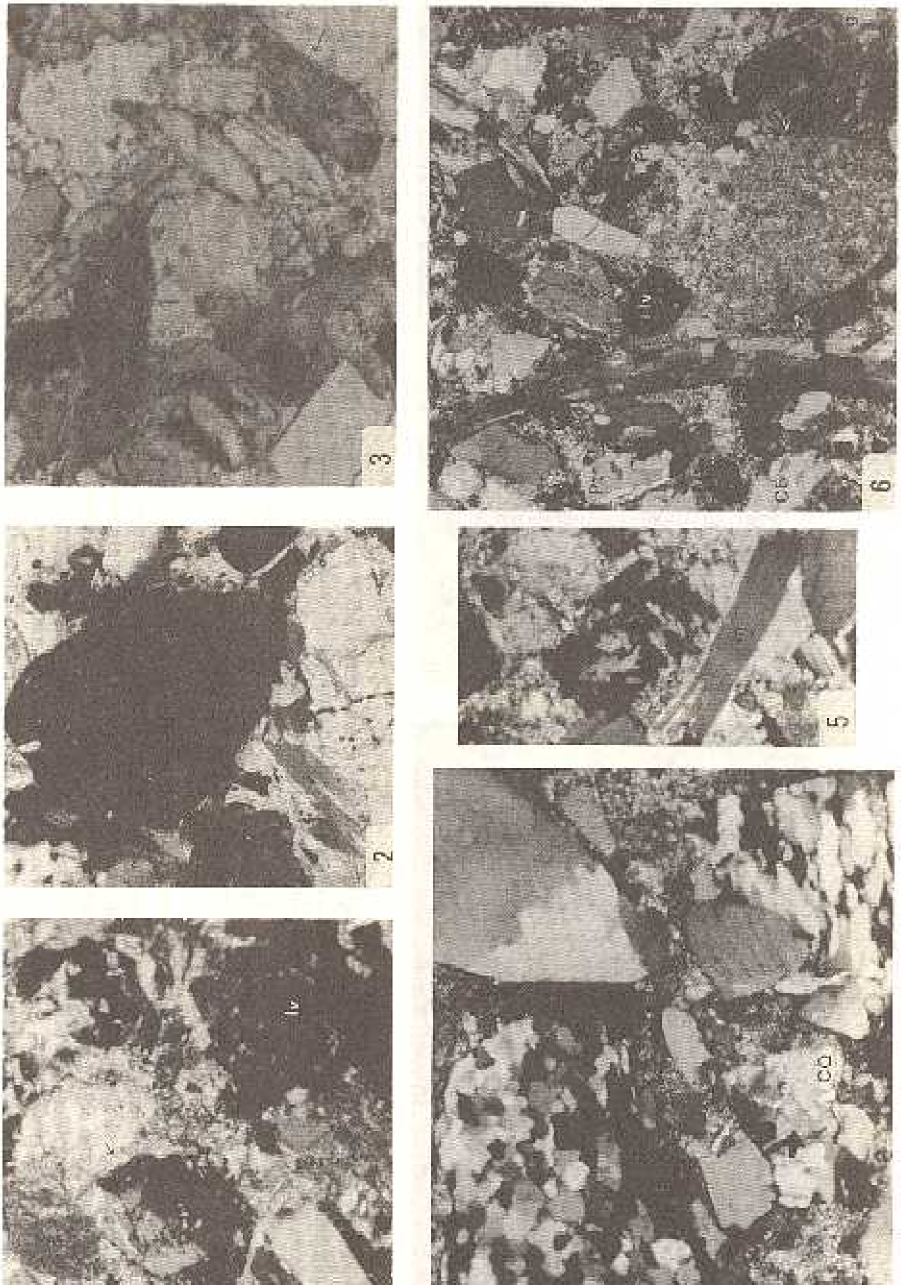
Gross composition

Compositionally, the sandstone sample population is quite homogeneous. Optical analyses are illustrated in Table 2.

All arenite components ranging from 0. 0625 to 2 mm in diameter were considered. According to Zuffa (1985) they can be subdivided into two main classes i.e. extrabasinal and intrabasinal arenaceous components; within the former a further subdivision has been performed with reference to carbonate and noncarbonate nature of clasts.

Noncarbonate extrabasinal grains (NCE)

The NCE fraction is represented by quartz, feldspars and lithic fragments. (Table 2 and Fig. 8).



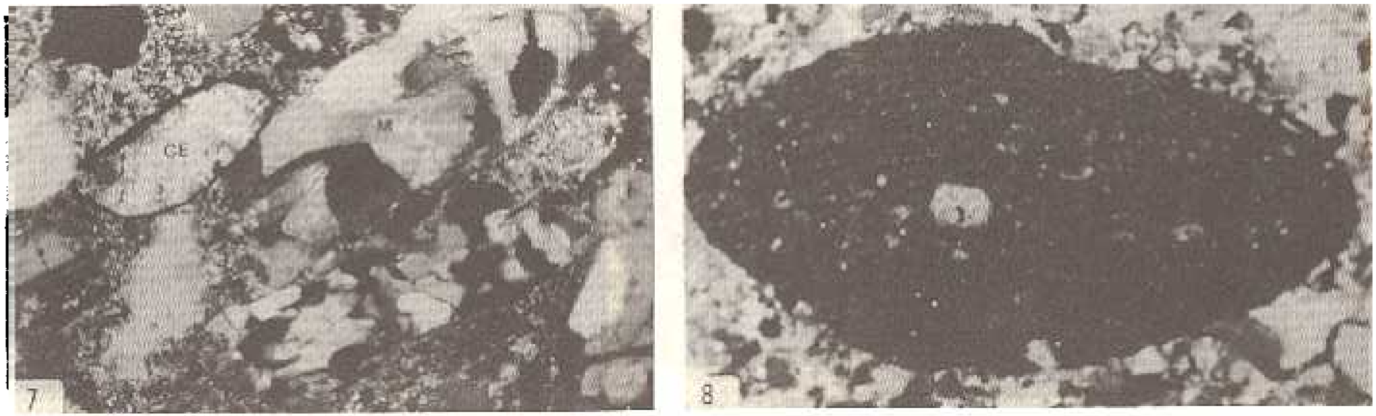


Fig. 8.—Photomicrographs of some lithic fragments from the arenites of MCF basin. 1), Acid-volcanic grain with hexagonal-bipyramidal quartz phenocryst (0.5 mm high), lv, volcanic lithic grain; 2), microlites of feldspar in black glassy ground mass (1.2 mm long); 3), pelitic rip-up clasts (polarized light); 4), policrystalline quartz some of which have a perfect orientation of elongate crystals with sutured contacts (0.8 mm long), CQ, calcite replacements on quartz; 5), serpentineschist (0.4 mm long), m, micas (biotite), 6), fossiliferous limestones (2.7 mm high), Pt, plutonic grain; CE, carbonate extrabasinal, Bi, bioclast; g, gastropod fgm; 7) schistose metamorphic composite (1.4 mm long), M, mollusc fgs with drusy sparite; 8) arenite limestone (4.3 mm long). All photomicrographs were taken with crossed nicols (except for the photom. n.3).

Fig. 8.—Microfotografías de algunos fragmentos líticos de las arenitas de la cuenca de MCF. 1), Grano volcánico ácido con fenocristales de cuarzo hexagonal bipiramidales (0.5 mm de altura), lv, grano volcánico lítico; 2), microlitos de feldespato en una masa negra cristalina (1.2 mm de longitud); 3), clastos pelíticos (luz polarizada); 4), cuarzos policristalinos alguno de los cuales tienen una orientación perfecta de los cristales alargados con contactos suturados (0.8 mm de longitud), CQ, reemplazamientos calcíticos en cuarzo; 5), esquisto serpentínico (0.4 mm de longitud), m, micas (biotita), 6), calizas fosilíferas (2.7 mm de altura), Pt, grano plutónico; CE, carbonat extracuencal, Bi, bioclasto; g, fragmento de gasterópodo; 7) compuesto esqistoso metamórfico (1.4 mm de longitud), M, fragmentos de moluscos con esparita en drusa; 8) caliza arenosa (4.3 mm de longitud). Nicoles cruzados en todas la microfotografías excepto en la nº 3.

Quartz

It is represented by either monocrystalline grains (x = 14.14 %), commonly with undulose and normal extinction, or polycrystalline grains (x = 15.93 %), with intragranular contacts commonly crenulate, sutured and straight. Sometimes it is characterized by recrystallized quartz fragments; quartz in metamorphic rock fragments is abundant (Table 2 and Fig. 8).

Feldspars

These are constituted both by k-feldspars and by plagioclase generally altered; the k-feldspar (x = 10.32 %) prevails over the plagioclase (x = 4.13 %). The latter has an albite-oligoclase composition (Table 2 and Fig. 9).

Tabla 2.—Modal analyses of the arenites of MCF basin. Q: Qs, monocrystalline quartz; Qp+Qm, polycrystalline quartz and quartz in metamorphic rock fgm; Qv, quartz in volcanic rock fgm; Qsd, quartz in sandstone; cQs, calcite replacing quartz (single grain); cQrf, calcite replacing quartz (in rock fgm). K: Ks, potassium feldspar (single grain); Kp, k-feldspar in plutonic rock fgm; Km, k-feldspar in metamorphic rock frg; Kv, k-feldspar in volcanic rock fgm; cKs, calcite replacing k-feldspar (single grain); cKrf, calcite replacing k-feldspar (in rock frg). P: Ps, plagioclase (single grain); Pp, plagioclase in plutonic rock frg; Pm, plagioclase in metamorphic rock frg; Pv, plagioclase in volcanic rock frg; cPs, calcite replacing plagioclase (single grain); cPrf, calcite replacing plagioclase (in rock frg). L: Lm, metamorphic rock frg; Lv, volcanic rock frg; chert, CaSt, carbonate-cemented siltstone; SiSt, noncarbonate-cemented siltstone; Clt, calcite replacing on fine-grained lithic fragments. Micas: Mc, muscovite; Mf, biotite and chlorites. Oth, other minerals; NCI (noncarbonate intrabasinal): Gl, glauconite and rip-up clasts. CE (carbonate extrabasinal): micrite limestones, fossiliferous limestones, arenite limestones and spatite limestone. CI (coeval carbonate intrabasinal): molluscs, bivalves, gastropods, ostreid fgm, and benthonic and planktonic foraminiferal tests. Lc, limeclasts. Cm, carbonate cement (sparite and microspar). Mtx, matrix. Q, total quartz; F, total feldspars (K+P); M, total micas (Mc+Mf).

Tabla 2.—Análisis modal de las arenitas de la cuenca MCF. Q: Qs, cuarzo monocristalino; Qp+Qm, cuarzo policristalino y cuarzo en fragmentos de rocasmetamórficas; Qv, cuarzo en fragmentos de rocas volcánicas; Qsd, cuarzo en arenisca; cQs, calcita reemplazando cuarzo (granos simples); cQrf, calcita reemplazando cuarzo (en fragmentos de rocas). K: Ks, feldespato potásico (granos simples); Kp, feldespato potásico en fragmentos de rocas plutónicas; Km, feldespato potásico en fragmentos de rocas metamórficas; Kv, feldespato potásico en fragmentos de rocas volcánicas; cKs, calcita reemplazando feldespato potásico (granos simples); cKrf, calcita reemplazando feldespato potásico (en fragmentos de rocas). P: Ps, plagioclasa (granos simples); Pp, plagioclasa en fragmentos de rocas plutónicas; Pm, plagioclasa en fragmentos de rocas metamórficas; Pv, plagioclasa en fragmentos de rocas volcánicas; cPs, calcita reemplazando plagioclasa (granos simples); cPrf, calcita reemplazando plagioclasa (en fragmentos de rocas). L: Lm, fragmentos de rocas metamórficas; Lv, fragmentos de rocas volcánicas; chert, CaSt, limolita cementada por carbonato; SiSt, limolita no cementada por carbonato; Clt, reemplazamientos calcíticos de fragmentos líticos de grano fino. Micas: Mc,moscovita; Mf, biotita y cloritas. Oth, otros minerales; NCI (intracuencal no carbonatado): Gl, glauconita y clastos arrancados. CE (carbonato estracuencal): calizas micríticas, calizas fosilíferas, calizas arenosas y calizas esparíticas. CI (carbonata intracuencal coetáneo): moluscos, bivalvos, gasterópodos, fragmentos de ostreidos, y caparazones de foraminíferos planctónicos y bentónicos. Lc, clastos calizos. Cm, cemento carbonatado (esparita y microsparita). Mtx, matriz. Q, total cuarzo; F, total feldespato (K+P); M, total micas (Mc+Mf).

Body N.	1	2	3	4	5	6	7
Qs	16,89	14,27	17,64	11,36	13,40	12,00	13,40
Qp + Qm	17,56	15,17	16,44	15,84	14,90	13,60	18,00
Qv	0,20	0,23	0,20	0,20	0,10	0,30	—
Qsd	0,68	0,37	0,72	0,52	0,30	—	—
cQs	3,20	3,27	1,80	4,00	6,80	5,80	6,50
cQrf	0,48	0,40	0,20	0,32	0,40	—	—
Ks	6,52	7,73	6,52	7,48	7,80	6,70	8,90
Kp	0,48	0,23	0,68	0,20	0,20	0,20	0,50
Km	1,12	1,27	1,04	1,80	1,40	1,30	1,00
Kv	—	0,20	—	—	—	—	—
cKs	1,48	1,03	0,72	0,92	1,40	1,00	1,70
cKrf	0,40	—	—	0,24	0,10	—	—
Ps	2,28	2,90	2,16	2,40	2,00	2,90	1,90
Pp	0,40	0,37	0,40	0,28	0,10	—	0,10
Pm	0,52	0,63	0,60	1,00	1,00	0,30	—
Pv	—	—	—	—	—	—	—
Psd	0,20	—	0,20	0,20	—	—	—
cPs	1,36	0,53	0,60	0,56	0,90	1,20	0,90
cPrf	0,20	0,20	—	—	—	—	—
Lm	1,40	4,73	4,26	6,12	2,60	4,40	1,80
Lv	1,27	3,63	3,72	4,16	1,30	2,40	1,30
ch	1,32	2,33	2,04	3,00	2,00	1,50	1,40
CaSt	0,20	0,40	0,24	0,60	0,10	—	0,10
SiSt	0,24	0,27	0,36	0,24	—	—	—
Clt	0,60	0,53	0,44	0,84	0,40	0,70	0,30
Mc	2,92	1,93	1,56	1,64	1,80	3,10	1,90
Mf	1,80	1,37	0,96	1,40	1,40	2,10	1,60
Oth	0,20	—	0,16	0,20	0,10	0,20	0,10
Gl	0,16	0,33	0,16	0,36	0,40	0,90	—
rip-up	5,24	2,93	2,44	2,52	4,80	1,80	2,60
CE	8,40	12,47	13,20	14,00	12,10	13,60	10,00
CI	3,28	4,98	5,22	5,44	4,80	4,60	7,00
Lc	0,76	0,20	0,32	—	—	0,20	—
Cm	18,00	15,10	15,00	12,16	17,40	19,20	18,50
Mtx	0,24	—	—	—	—	—	0,20
	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Q/Q +F	0,73	0,69	0,74	0,68	0,71	0,70	0,72
K/F	0,68	0,70	0,69	0,71	0,73	0,68	0,81
Qs/Q	0,51	0,52	0,53	0,48	0,56	0,56	0,52
Mc/M	0,62	0,58	0,62	0,54	0,56	0,60	0,54

Rock fragments

Rock fragment analyses are fundamental for arenite provenance studies. Fragments of metamorphic and plutonic (x = 50.86 %), sedimentary (x = 42.71 %), and volcanic (x = 6.43 %). rocks have been recognized (Lm-Lv-Ls plot Fig. 10c).

Metamorphic lithic fragments come from low-to-middle-grade metamorphic lithotypes: quartzites, serpentineschists, micaschists. (Fig. 8).

Plutonic components do not exclude a provenance from granitoid and middle-to-high grade metamorphic rocks (gneisses).

The sedimentary component is mostly constituted by extrabasinal carbonate grains; minor components are represented by chert, siltstones and sandstones (Table 2 and Fig. 8).

Volcanic components (mostly of dacitic-rhyodacitic composition) are scarse in the terrigenous grain population.

Micas

They are represented by muscovite (Mc = 2.12 %, mean value) and biotite plus chlorite (Mf = 1.52 %, mean value) with subordinate chlinochlore.

Noncarbonate intrabasinal grains (NCI)

The NCI fraction is represented by glauconite, pelletoidal grains, as a replacement product on phyllosilicate grains and sometimes as a filling of fossil tests. All glauconite occurrences were considered authigenic. Moreover abundant intraformational clayey and silty rip-up clasts are present in all samples and reach up to more than 3%. (Table 2 and Fig. 8)

Carbonate extrabasinal grains (CE)

This fraction is present in all samples in an amount varying from 8.4 % to 14.0 %. The lithotypes most commonly represented are: micrite limestones, fossiliferous limestones sometimes with pellets and/or microforaminifers, recrystallized limestone and spatic carbonates (Table 2 and Fig. 8).

Coeval carbonate intrabasinal grains (CI)

This component is only represented by fossiliferous clasts in moderate percentage (x = 5.05 %). They consist particularly of abundant molluscs (bivalves, gastropods, ostreid fragments) and benthonic and planktonic foraminiferal tests.

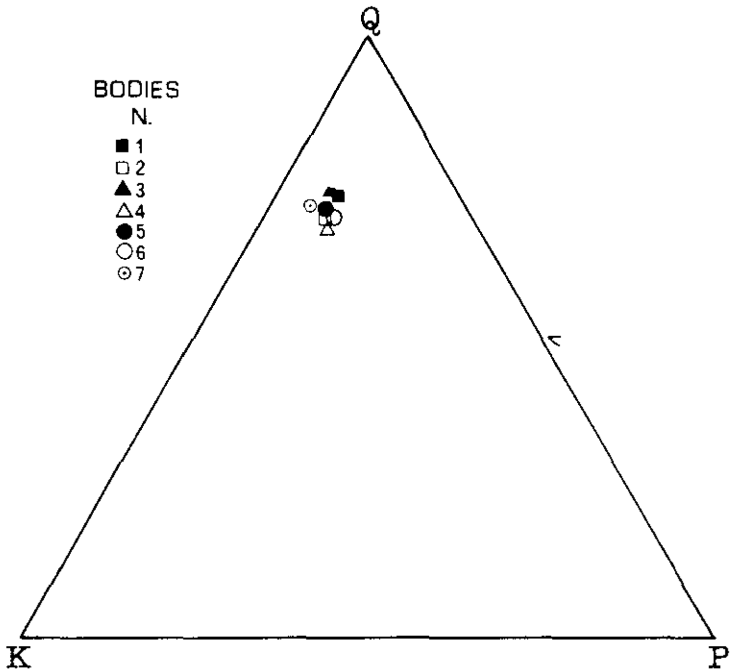


Fig. 9.—QKP ternary plot of arenite bodies of MCF. Q, quartz, K, potassium feldspar, P, plagioclase.

Fig. 9.—Diagrama ternario QKP de los cuerpos de arenitas de MCF. Q, cuarzo, K, feldespato potásico, P, plagioclasa.

Cement

Calcite cement is abundant in all samples. Two fabric types of calcite cement have been well-documented: syntaxial overgrowths on molluscan fragments and granular (drusy mosaic with crystal size from 0.0004 mm to 0.0010 mm, i.e. meteoric genesis ?). These two calcite cement generations reflect both the new-formed crystals (authigenic) and replacement processes. Pore-filling calcite is present in large percentages.

Matrix

This (< 0.0625 mm in size) is very scarse, or almost absent; it is formed by micrite and siliciclastic particles.

Textural features

Arenite grain size commonly ranges from middle-fine to very coarse.

From a textural point of view, the studied arenites are commonly mature and are moderately sorted. Grain-shape varies from subangular to subrounded for quartz grains, while feldspars are commonly angular or subangular; among lithic fragments, chert is usually subangular, while carbonate extraclasts are commonly represented by subrounded to rounded grains (Fig. 8).

Diagenic processes

The main diagenic process results linked to the cementation phase. In fact, considering the virtual absence of matrix, the arenites underwent a premature diagenesis characterized by a rapid formation of calcitic cement which inhibited mechanical compaction of sediments (Biørlykke, 1983; Hird & Tucker, 1988).

Timing and spacing of calcite cement precipitation is still a matter of delate. It is probably due to turbulent courrents occurred into sedimentary basins with porewater oversaturated in $CaCO_3$.

DISCUSSION

Data from table 2 were elaborated in order to apply Zuffa's (1985) classification and are represented in a triangular plot (Fig. 10a); the petrofacies is characterized by the predominance of NCE and CE constituents and by the common presence of NCI grains. The same distinction is emphasized by Q-F-L plots (Fig. 10b) where carbonate extrabasinal grain were considered in calculating L-values together with other rock fragments, chert included. This petrofacies (mean value: $Q_{47,}$ F_{18} L_{35}) is defined as quartzolithic petrofacies (sensu Dickinson, Lawton & Inman, 1986) or feldspathic litharenite (sensu Folk, 1980).

Data on rock fragments were plotted on a triangular diagram where metamorphic, volcanic and sedimentary lithic fragments are distinguished (Lm, Lv, and Ls respectively; Fig. 10c).

In order to evidence and compare the modal analyses of the arenites, some petrographic parameters have been computed (Q/Q+F, K/F, Mc/Mt, Qs/Q; Table 2 and Fig 11). Fig.11 diagrams have been drown with the method of Chiocchini & Cipriani (1984) and of Ardanese *et al.* (1983;1987) focused on the identification of source areas, i.e. plutonic (granitoid) and metamorphic source rocks.

Almost all the samples occupy the upper right quadrant, except for the samples of body n. 4 which partly are slightly shifted to the left.

PROVENANCE

Detrital modes of arenites indicate a local provenance from recycling of old-sedimentary rocks eroded from the adjacent Apennine chain (Figs. 12, 13

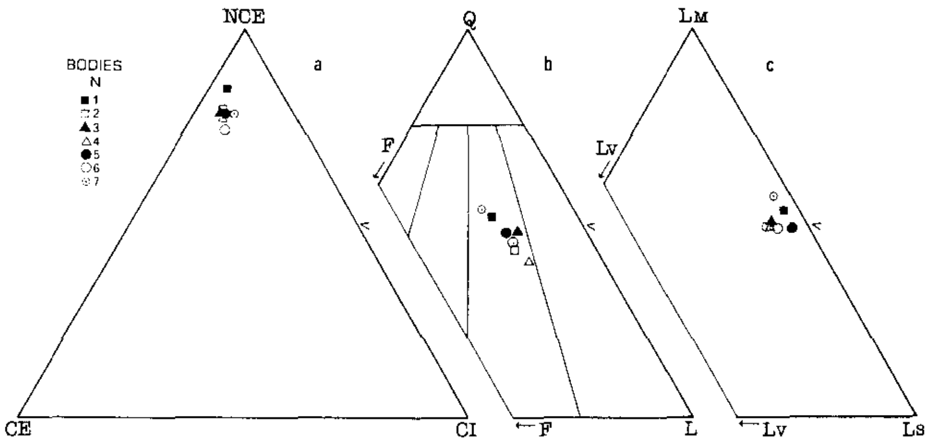


Fig. 10.—Composition of arenite bodies of MCF: **a**, framework classification; NCE, noncarbonate extrabasinal; CE, carbonate extrabasinal; CI, carbonate intrabasinal; **b**, Q, quartz, F, feldspar (including plutonic rock fgm), L, lithic rock fgm. **c**, Lm, plutonic + metamorphic, Lv, volcanic and Ls, sedimentary rock fgms.

Fig. 10.—Composición de los cuerpos de arenitas de MCF: **a**, clasificación de la trama; NCE, extracuencal no carbonatado; CE, extracuencal carbonatado; CI, intracuencal carbonatado; **b**, Q, cuarzo, F, feldespato (incluyendo los fragmentos de rocas plutónicas), L, fragmentos de rocas líticas. **c**, Lm, plutónicas + metamórficas, Lv, volcánicas y Ls, fragmentos de rocas sedimentarias.

and 14). In part, the arenites studied derive from a multirecycling process of adjacent *Marnoso-Arenacea* Formation. This hypothesis is also documented both from a strong increase of quartz, K-feldspar (K>P) and muscovite (Mc>Mf). This clearly results from numerous cycles of transport and erosion, each cycle contributing to progressive increase in roundness and loss of unstable minerals (Potter, 1978). In fact, when correlating the data here obtained with those of the *Marnoso-Arenacea* Formation (Chiocchini & Cipriani, 1986; Ardanese *et al.*, 1987) it may be noted that these samples fall in opposite quadrants (Fig. 13). The quadrant of the samples here analysed indicates the field of metamorphic rocks; therefore, the provenance of the granitoid plutonic rocks + low-to high-grade metamorphic rocks may be found in the adjacent *Marnoso-Arenacea* Formation (Gandolfi, Paganelli & Zuffa, 1983; Valloni & Zuffa, 1984). Volcanic grains with a dacitic-rhyodacitic composition and hypoabissal quartz come from volcaniclastic horizons, e.g. *Bisciaro* Formation (Guerrera *et al.*, 1986; Ardanese & Capuano, 1990). These volcaniclastic events, are related to volcanism calc-alkaline type, and are likely linked to the Oligo-Miocene compressive tectonics of the Mediterranean area. As for the sedimentary components, the large amount of carbonate extrabasinal grains derives both from allochthonous units of the Ligurids and from the «autochthonous» Umbro-Marchean Sequence (Miocene carbonates and marls).

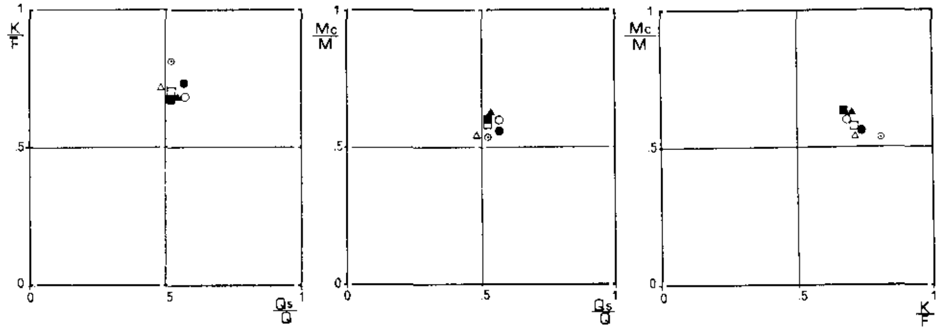


Fig. 11.—Correlation diagrams of quartz, feldspar and micas content of arenite bodies of MCF basin.

Fig. 11.—Diagramas de correlación del contenido en cuarzo, feldespatos y micas de los cuerpos areníticos de la cuenca MCF.

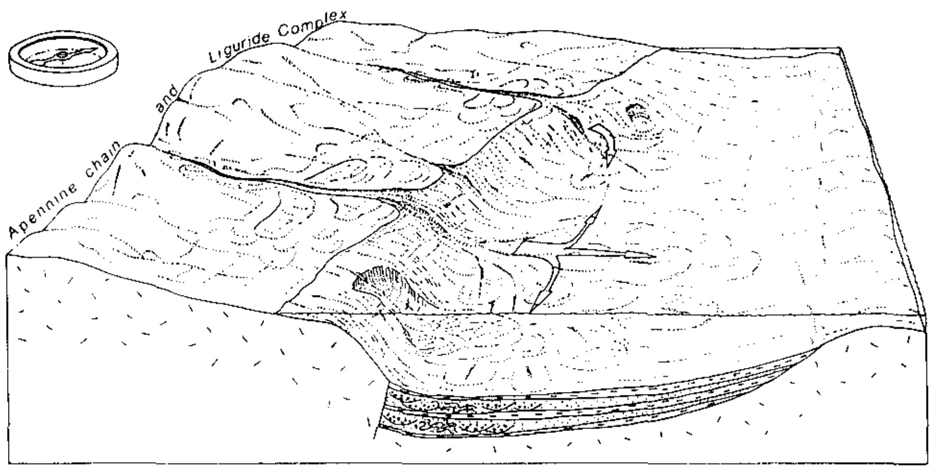


Fig. 12.—Paleogeographical reconstruction showing the provenance and dispersal pattern of rudite and arenite bodies of MCF basin. A terraced fan-delta during a lowstand period, undergoes remobilization into a deep-water environment (after Capuano *et al.*, 1989, modified).

Fig. 12.—Reconstrucción paleogeográfica mostrando la procedencia y el modelo de dispersión de los cuerpos de ruditas y arenitas de la cuenca MCF. Un fan delta aterrazado durante un periodo de nivel del mar bajo sufre removilización en ambientes de aguas profundas (según Capuano *et al.*, 1989, modificado)

CONCLUSION

In the Montecalvo in Foglia basin the rudites are distributed and statistically divided into five size classes of pebbles to cobbles. Compositionally, they are prevalently constituted by carbonate, chert and greywacke clasts. The

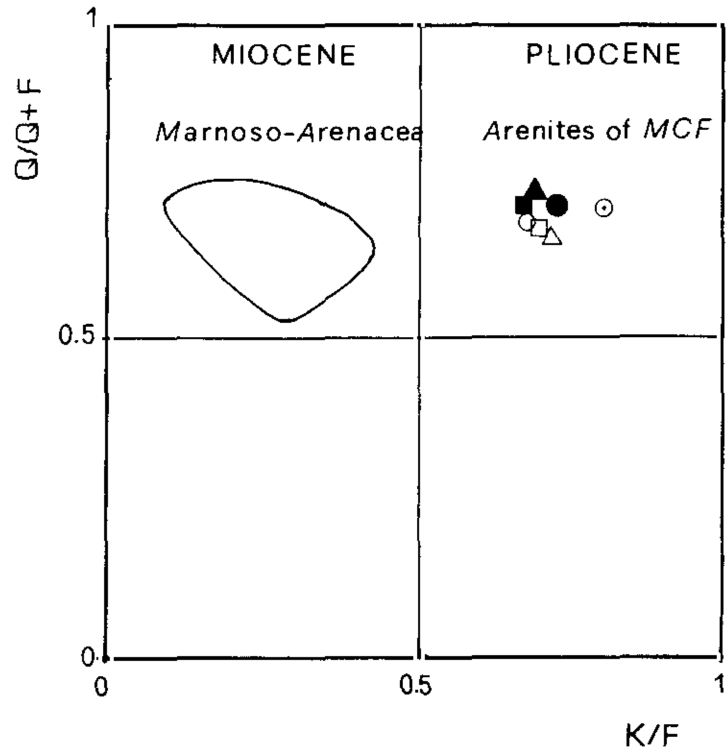


Fig. 13.—Petrographic correlation between *Marnoso-Arenacea* (after Chiocchini & Cipriani, 1986) and arenite bodies of MCF basin. (For explanation see text).

Fig. 13.—Correlación petrográfica entre la *Marnoso-Arenacea* (según Chiocchini y Cipriani, 1986) y los cuerpos arenosos de la cuenca MCF (ver el texto para la explicación).

provenance may be assumed to the west and northwest where the alloch thonous chaotic units (Ligurian Complex, Montefeltro area) are outcropping.

Petrographic data show that the composition of the arenite bodies is the same in the whole basin. One quartzolithic or feldspathic litharenite petrofacies with mean values Q_{47}, K_{18}, L_{35}, has been defined. It includes several components of sedimentary, granitoid plutonic and metamorphic (from low-to-high grade to, a mostly, low-grade), and volcanic grains. The great variety of rock fragments suggests a recycled orogene provenance (Dickinson & Suczek, 1979; Dickinson *et al.*, 1983; Ingersoll & suczek, 1979; Zuffa, 1987; Capuano & Proietti, 1988). In fact, a significant detrital input results from erosion of a hinterland, mainly constituted by the miocenic terrigenous turbiditic sequence (i.e. *Marnoso-Arenacea* Formation). The palaeovolcanic grains (Zuffa, 1985) derived from the erosion of miocenic volcaniclastic horizons (i.e. *Bisciaro* Formation). Provenance from ophiolitic units, probably present in the Montefeltro area, cannot be excluded. The sedimentary components are

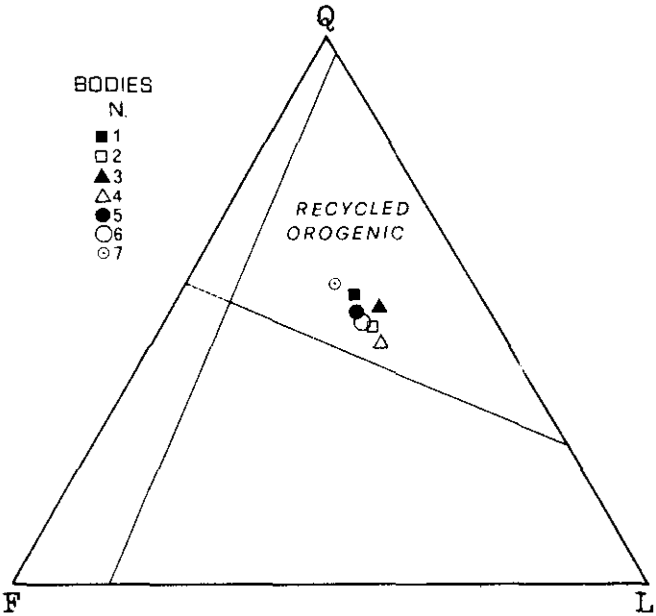


Fig. 14.—Provenance of arenites of MCF basin (after Dickinson *et al.*, 1983).
Fig. 14.—Procedencia de las arenitas de la cuenca MCF (según Dickinson *et al.*, 1983).

largely represented by extracarbonate grains. Their provenance area may be found both in the chaotic units (Ligurds) and in the Miocene carbonates and marls (Umbro-Marchean sequence).

During the Early Pliocene there was a direct relationship between source area and depositional basin. In fact, the rudite and arenite grains of western provenance (Fig. 12) could be temporarily accumulated (residence time) and later recycled, reworked and cannibalized in connection with tectonic activity and sea level variations (Capuano, 1990c). Such deposits, from the diagenetic point of view, result undercompacted; the rapid cementation inhibited compaction of sediments. The rapid formation of cement occurred through the circulation in the basin of warm saline waters supersatured by carbonate. In this basin, climatic factors had fundamental effect on arenite composition.

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