

Gravel washing wastes from Jarama river deposits (Spain): an undervalued natural raw material

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Abstract This work presents the main characteristics of 97 quarry wastes, collected in 23 gravel pits, from the Jarama river area, Madrid province, Spain. In this area, more than 2.5×10^6 ton of silty-clay waste are generated every year, and no applications have as yet been defined for them. This work is the first systematic study of the fine fractions generated from the Jarama river quaternary deposits, playing part in the comprehension of this complex terrace systems. Quartz, potassium feldspar, plagioclase, calcite, and complex mixtures of phyllosilicates, such as smectite, illite, kaolinite, chlorite and illite/smectite mixed layer, have been detected. Two sets of waste which are recognized according to the calcite content, have been directly related with the terrace level benefited in the Jarama river, and the position along the valley. Calcite concentrates in the wastes produced in the lower course, where Henares and Tajuña tributaries promote an extensive change in the geochemistry of

underground water, and locally, in the petrology of quarried conglomerates. This clear distinction by location between calcite-bearing and calcite-free wastes is essential for potential applications, such as soil conditioning, raw materials for brick or tiles, etc. The wastes studied can be considered as a potential source of industrial raw materials because of their uniformity and large volume. This suggestion is now being carried out, with an attempt at assessing the possibilities of using these mining wastes as ceramic raw materials.

Keywords Jarama river · Waste · By-product · Raw material · Gravel mud

Introduction

Spain is one of the greatest aggregate users in Europe. The total production in 2005 (530×10^6 ton) was the second after Germany (ANEFA 2006). This volume represented an increase of 5.3% over 2004, and was twice the production of 1997. At the present time, the Spanish average consume of aggregates per capita is 10.7 ton a year, surpassing largely the European average value of 7.0 ton a year.

Madrid province, where the study zone is located, is the fourth aggregate supplier in Spain (48×10^6 ton in 2005), but it is statistically the lowest per capita consumer (8.0 ton a year) due to the high population density. The extensive demand for aggregates in the province caused an increase in the price to 6.6 €/ton, in April 2005, following the rising tendency of the last 6 years.

In 2003 about 50 sand and gravel pits were active in Madrid province, and two thirds of them dug Jarama

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river conglomerates (Blanco García 2004). This work deals with wastes collected in 23 of these Jarama river pits, and reflects the characteristics of the primary source of sedimentary aggregates in this province, and one of the most important of the country.

In 2000–2002, the average volume of conglomerates quarried from Jarama sedimentary system was estimated as 25×10^6 ton annually. Considering that the Jarama river deposits include at least 10–15% of silt and clay (gravel providers, personal communication) that must be removed by washing to produce saleable aggregates, the volume of silty-clay waste generated every year is more than 2.5×10^6 ton (Blanco García 2004). This huge volume of waste must be studied accurately, in view of the present environmental and management problems, as well as the prediction of future volume increases.

On the other hand, the study of Jarama river terraces is complex due to the homogeneity of facies and compositions. Several authors have defined to 15 terrace levels for the river Jarama (e.g. Hernández Pacheco and Aranegui 1927; Riba 1957; López and Pedraza 1976; Cabra et al. 1983), but their total correlation and continuity has not been established (Alonso and Garzón 1994). The problem of terrace demarcation has been widely faced, studying soil profiles (Aleixandre et al. 1974; Pérez-González et al. 1974; Gallardo et al. 1987), the composition of sand (Aleixandre et al. 1977; Fort and Díaz 1987), and the petrology of coarser fraction (Asensio Amor and Vaudour 1967). The argillaceous particles have been also studied, but only in isolated soil profiles (Vaudour 1979). The present study was undertaken to analyse the composition of the wastes generated by washing Jarama river terraces and their variations as a function of geological features, such as: age, location or substrate type of the quarried terrace, influence of tributaries, etc. This is the first systematic study of the silty-clay fraction in the Jarama river quaternary deposits, playing part in the comprehension of this complex terrace systems. Supplementary technological features, as plasticity behaviour, are also studied, with the aim of assessing the potentiality of these wastes as raw material in the heavy clay industry.

Study area

Location

The Jarama river is the most important fluvial system in central Spain, and comprises about three quarters of Madrid province. The headwaters are above 2,000 m in

the Somosierra massive, descending to 485 m at town of Aranjuez, where flows in the Tajo river after 150 km.

The area studied covers the lower 90 km of the river, comprising the middle and lower courses. On the right margin the Jarama river receives the waters of the Guadalix and Manzanares tributaries. On the left margin it receives the river Henares, that limits the middle and lower courses. The Tajuña river flows into the Jarama only 10 km before the confluence with the Tajo river (Fig. 1).

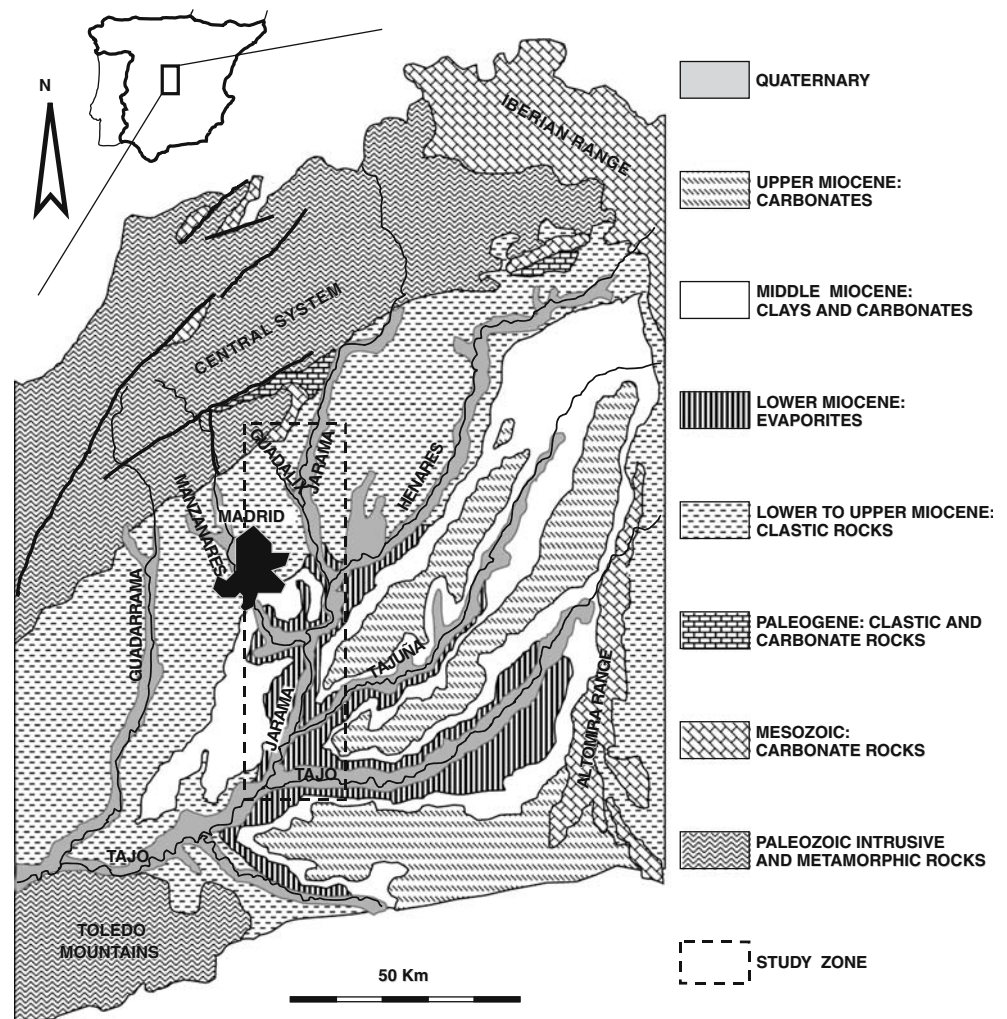
Geological setting

The Jarama river upper course drains primarily from the central Spain mountain range (Central System), which consists of large exposures of granitoides (granites, granodiorites and tonalities) that intrude metamorphic basement (gneiss, quartzites and slates). Downstream, the river dissects the sedimentary Madrid Basin from north to south (Fig. 1). This basin is filled by a thick Tertiary continental sequence that surpasses 3,500 m (Racero 1988). The sedimentation during the Tertiary was controlled by the tectonic activity of the borders: Central System, Iberian Range, Toledo Mountains and Altomira Range (Giner and De Vicente 1995). Thus, the strata represent a continental sinorogenic clastic wedge deposited following the Alpine build-up of the basin borders.

Paleogene deposits are mainly identified by boreholes and represent approximately two thirds of the total filling. They include lacustrine carbonates and clastic deposits, being the initial infilling of the basin (Arribas et al. 1983). Neogene sediments are mostly Miocene and correspond to complex interconnected prograding alluvial fans (Junco and Calvo 1983). Their typical proximal facies are conglomerates and gravels, changing laterally to arkosic sands (Fig. 1). Clays, evaporite and carbonate lacustrine deposits represent the distal facies of these alluvial fans and were developed in an arid sub-arid climate (Alonso Zarza et al. 1989; Roquero et al. 1996).

During the early Miocene, complex evaporitic associations (gypsum–anhydrite–glauberite–thenardite–halite), clays and magnesite–dolomite were accumulated in the central area of Madrid Basin (García del Cura 1979). The middle Miocene deposits maintained the facies distribution, where alluvial sediments become coarser towards the basin borders, but the evaporitic materials, composed only of gypsum, were less developed. The volume of lacustrine carbonates increases upwards as the evaporites disappear. The

Fig. 1 Geological sketch of the Madrid Basin and location of study zone



marginal facies of these lacustrine deposits present an important development of clay minerals, where a great accumulation of bentonites, and some of the most important deposits of sepiolite in the planet are found (e.g. Megías et al. 1982; Galán and Castillo 1984; Leguey et al. 1985; Castillo 1987). In other areas of the palaeomargins of those lakes tabular carbonates, chert and green or pink clay strata are recognized (Wright et al. 1997; De Santiago Buey et al. 2000; Bustillo 2001; Bustillo et al. 2002).

During Pliocene and Quaternary times the modern hydrography patterns were established. Pliocene erosion surfaces, covered by clastic deposits, occurred in several areas in the Central System (Portero et al. 1991; Tortosa et al. 1997). These are represented by a large variety of clastic sediments, mainly conglomerates—the so called “raña”—grain and matrix supported, typically composed of quartzite pebbles, red clays, sand and silt (Cabra et al. 1983). Their distribution is reduced because of the Quaternary erosion process, and are considered as the main sediment

“suppliers” of the Jarama river sedimentary system (Asensio Amor and Vaudour 1967).

Jarama river terraces

The homogeneity of facies and gravel composition, and the lack of good outcrops, especially the older deposits, make difficult the study of Jarama river deposits. Most authors classify and group the Jarama river terraces according to their topographical height above the present channel. As a result, and integrating sedimentological, stratigraphical, tectonical and geomorphological criteria, the 15 terrace levels can be divided into three systems (Alonso and Garzón 1994):

Higher terrace system Here are included terrace treads that appear above +30 to 40 m, up to +170 m. These earliest-to-mid Pleistocene age deposits form isolated fragments, vertically disconnected and colluviated, and their sequential distribution of facies implies lateral shifting of channels and a well-developed flood plain. The most common sequence is

a conglomerate basal body changing upwards into sands and later into clays, strongly modified by pedogenic features.

Intermediate terrace system This system include deposits of mid-to-late Pleistocene age, hanged between +12 m and +30 to 40 m. Differentiated levels can be recognized along the middle course, but are condensed downstream, giving a thick multi-episodic series, in response to the tectonic tilting of the basin. In the lower course, the presence of a highly soluble, Miocene gypsum-bearing bedrock, has been pointed out as a symsedimentary controller of the terraces thickness, which can exceed 40 m (Pérez-Gonzalez 1971). Classical point bar fining-upwards sequences of a medium- to high-sinuosity river are differentiated in them.

Lower terrace system It groups conglomerates deposited at least at 3,000 BP, and located up to +12 m above the present river. The aggradation resulted in a single fining-upwards sequence, and represents channel infilling and abandonment. It displays basal conglomerates, turning into sands and gravels, and finishing in a very homogeneous unit composed of ripened silts and clays, corresponding to the recent river floodplain.

Table 1 Factors and principles considered in the selection of gravel pits

Factor	Principles
Geology	Type and age of mined terrace (actual floodplain + Lower terraces, Intermediate terraces or Higher terraces) Type of terrace bedrock (arkoses, marls, clays or evaporites)
Localization	Distance of the mined deposit to the actual Jarama river thalweg and to the valley margins, middle or lower course, etc.
Conglomerates processing	Type of quarrying process (dry or wet) Type of screening or washing equipment (dry or wet screening, grizzly screen, trommel, multi-deck screen, etc.)
Waste elimination and accumulation process	Type and dimensions of the settling ponds, presence of hydrocyclones and/or waste thickeners, pumping, length of channels, etc.
Company type	Multinational (big) or “familiar” (small) companies
Interest of the company	The cooperation of the companies is a key factor, because of the access to the processing plant, sampling and the production data

Sampling and procedures

As the main goal of this study was to examine the composition of waste generated by washing Jarama river terraces, and to determine the key parameters that control the uniformity, an inventory of factors to be consider was initially established (Table 1). As a result, 23 gravel pits were selected for this study (Table 2).

The field work was focused on the collection of wastes: about 15–20 l of every slurry, water rich waste, and 3–8 kg of moderately dry mud, were sampled. They were labelled by one letter (“J”, from Jarama), and four numbers: the two first numbers represent the pit sampling order, and the last two digits are the sample order in each gravel pit. A population of 97 wastes is considered in this study.

To prepare the wastes for the laboratory studies, a series of preliminary treatments was required. Samples were air desiccated on plastic trays and a first analysis was completed, checking the content of pebbles or plant matter. Once the moisture had been reduced to handling values, samples were manually mixed to promote homogenization, and completely oven-dried at 60°C.

The semi-quantitative mineralogical analyses were carried out by X-ray diffraction (XRD) techniques: about 2 g of sample were hand milled below 53 µm in an agate mortar, and used for the determination of the bulk mineralogy (random powder method). For the detailed study of phyllosilicates, 100 g of waste were treated to eliminate components preventing complete dispersion (e.g. carbonates, sulphates, organic mater, etc.). The <2 µm (clay minerals) and 2–20 µm (fine-medium silt) fractions were extracted by sedimentation techniques and analysed on “thick” glass slides (5 mg cm⁻²) by XRD, according to Moore and Reynolds (1989): samples were chemically treated (a: ethylene glycol, detecting expandable minerals; and b: dimethyl sulphoxide, to differentiate chlorite and kaolinite) and thermally treated (550°C for 2 h, to study the behaviour of phyllosilicates). The samples were analysed using Cu K_α radiation, (Philips® PW-1710 diffractometer), graphite monochromator, 40 kV and 40 mA, and sensitivity of 2 × 10³ cps. The measuring ranges were 2–75 or 2–50°2θ, goniometer speed of 0.04 or 0.05 and time constant of 0.4 or 1 s, for random powder or glass slides, respectively.

About 50 g of dry waste were used for the qualitative mineralogical analyses of sand (0.06–0.4 and 0.4–2 mm) and gravel (>2 mm) fractions, recovered by wet sieving on a 500 ml dispersion. The gravel particles were analysed with a binocular microscope, while

Table 2 General description of the studied gravel pits, ordered by location from north to south

	Pit	Terrace system	Terrace bedrock	
Middle course	J17	Lower (include actual floodplain)	Arkoses	
	J18	Intermediate	Arkoses	
	J19	Intermediate	Arkoses	
	J16	Lower (include actual floodplain)	Arkoses	
	J14	Lower (include actual floodplain)	Arkoses	
	J20	Higher	Arkoses	
	J15	Lower (include actual floodplain)	Arkoses	
	J10	Lower (include actual floodplain)	Arkoses	
	Lower course	J08	Lower (include actual floodplain)	Evaporites, clays
		J06	Intermediate	Evaporites, clays
J04		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J05		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J22		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J07		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J23		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J03		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J13		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J02		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J12		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J09		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J01		Intermediate + Lower (include actual floodplain)	Evaporites, clays	
J21	Intermediate + Lower (include actual floodplain)	Evaporites, clays		
J11	Intermediate + Lower (include actual floodplain)	Evaporites, clays		

sandy fractions were used to prepare thin sections, after cementing with resins, and studied by optical microscopy. Each thin section was etched and stained using HF and sodium cobaltinitrite for feldspars, and alizarine and potassium Fe-cyanide for carbonate grains.

To determine the plastic behaviour, and ascertain the potential applications of wastes in the heavy clay sector, Atterberg limits were calculated on the basis of UNE 103-103 1994 and UNE 103-104 1993 standards.

Results

General features

The 23 gravel pits covered in this work represent about 70% of the quarries that beneficiate Jarama river deposits. Their main general characteristics are summarized in Table 2, listed by location from north to south.

Quarrying activity is concentrated in the lower course, where 15 gravel pits were sampled. In this sector of the river, Lower terraces overlap Intermediate terraces (inverted terraces), being mined as a whole (Table 2). Thus, waste generated in the lower course is a mixture from both terrace systems which are considered together in this work. In addition, in this southern sector, Jarama valley has prominent margins at both sides with a conspicuous rectilinear pattern,

where the evaporitic and clayey tertiary bedrock is exposed. In the upper part of these scarps the Higher Jarama river terrace treads (+30 to 40 m above the actual channel) are found. These deposits are hardly mined due to the intense cementation.

The middle course presents a normal (stepped) terrace distribution, where the mined terraces can be distinguished by their topographical distribution. In this sector of the river, companies are mostly located in the Lower terraces and in the actual floodplain deposits (less than +12 m above the river), due to the water accessibility. J18 and J19 are the only pits beneficiating the Intermediate terrace system, and were selected for this study. Conglomerates dug from the Higher terraces (J20 pit), are transported down, close to the river, for the washing process.

Arkosic sands are the bedrock of the terraces along the middle course, while evaporites and clays are the bedrock along the lower course. The transition between arkoses and evaporites is verified by lateral facies change, where a marly clayey unit was developed. Unfortunately, no gravel pits are located in this bedrock area.

Mineralogical composition

The mineralogy of the 97 wastes consist of phyllosilicates (15–85%), quartz (5–48%), potassium feldspar (tr-32%) and plagioclase (tr-35%) (Tables 3, 4, 5; Fig. 2). Calcite, and gypsum in particular, are not

Table 3 Mineralogical composition and plasticity values of sand and gravel washing wastes from Jarama river Middle course

		Bulk mineralogy (%)							2–20 µm (%)				<2 µm (%)					Plasticity (%)			
		Qtz	Kfs	Pl	Cal	Dol	Gp	Hem	Phy	Ill	Sm	Kln	Chl	Ill	Sm	Kln	Chl	I/S	Wl	Wp	Ip
Lower terraces	J1701	8	5	8	tr	tr	–	tr	79	47	tr	53	tr	14	66	20	tr	tr	44	25	19
	J1702	10	tr	9	tr	tr	–	tr	81	48	tr	52	tr	7	80	13	–	–	46	23	23
	J1703	6	tr	9	tr	–	–	–	85	46	tr	54	tr	5	82	13	–	–	62	30	32
	J1704	10	tr	8	tr	–	–	tr	82	45	tr	55	tr	10	74	16	tr	tr	74	33	41
	J1601	45	7	7	tr	–	–	–	41	52	–	48	tr	21	48	31	–	tr	28	18	10
	J1602	39	8	6	tr	–	–	–	47	55	–	45	tr	12	65	23	–	tr	32	21	11
	J1603	20	6	10	tr	–	–	tr	64	57	–	43	tr	17	59	24	–	tr	54	28	26
	J1604	12	7	10	–	–	–	–	71	61	–	39	tr	13	69	18	–	–	58	31	27
	J1605	7	6	5	tr	–	–	–	82	60	–	40	tr	14	68	18	–	tr	61	29	32
	J1401	17	19	14	tr	tr	–	–	50	61	tr	39	tr	18	60	22	–	tr	37	24	13
	J1402	13	11	9	–	tr	–	–	67	56	tr	44	tr	19	62	19	–	tr	64	29	35
	J1403	25	13	20	tr	tr	–	–	42	61	tr	39	tr	16	68	16	tr	tr	37	26	11
	J1404	31	17	16	–	tr	–	tr	36	58	–	42	tr	16	61	23	tr	–	22	18	4
	J1405	26	6	5	–	–	–	–	63	59	tr	41	tr	14	70	16	–	–	45	26	19
	J1406	15	12	13	–	tr	–	–	60	55	tr	45	tr	17	60	23	tr	tr	52	30	22
	J1501	10	15	26	tr	–	–	–	49	32	tr	68	tr	5	90	5	–	–	nd	nd	nd
	J1502	9	10	34	tr	–	–	–	47	33	tr	67	–	5	89	6	–	–	nd	nd	nd
	J1503	16	10	20	–	–	–	–	54	54	tr	46	–	12	76	12	–	–	24	20	4
	J1504	48	9	tr	–	–	–	–	43	42	tr	58	–	13	78	9	–	–	32	20	12
	J1505	11	5	11	–	–	–	–	73	48	tr	52	tr	11	78	11	–	–	61	33	28
J1001	12	10	22	tr	–	tr	tr	56	57	tr	43	tr	9	81	10	tr	–	40	23	17	
J1002 ^a	16	9	18	tr	–	–	–	57	58	tr	42	tr	7	83	10	tr	–	57	28	29	
J1003 ^a	21	7	10	tr	–	–	–	62	58	tr	42	tr	10	78	12	–	tr	50	27	23	
J1004	27	12	20	–	–	–	–	41	57	tr	43	tr	10	78	12	–	tr	32	24	8	
J1005 ^a	12	6	10	–	–	–	–	72	57	tr	43	tr	8	80	12	–	–	59	32	27	
Intermediate	J1801	29	5	5	tr	tr	–	–	61	27	tr	73	–	11	56	33	–	tr	42	25	17
	J1802	22	5	5	–	–	–	tr	68	28	–	72	–	12	52	36	–	–	48	27	21
	J1803	14	5	6	–	tr	–	–	75	30	–	70	–	12	55	33	–	–	55	27	28
	J1901	19	16	5	tr	–	–	–	60	28	tr	72	–	12	56	32	–	tr	37	23	14
	J1902	5	5	5	–	–	–	–	85	30	tr	70	–	10	65	25	–	tr	90	38	52
	J1903	14	5	5	tr	–	–	–	76	29	tr	71	–	9	62	29	–	–	70	35	35
	J1904	16	7	5	–	–	–	–	72	28	tr	72	–	13	60	27	–	tr	65	32	33
Higher	J2001	5	5	5	10	tr	–	tr	75	37	–	63	tr	11	75	14	–	tr	54	24	30
	J2002	25	24	16	20	–	–	–	15	59	tr	41	tr	15	63	22	tr	–	nd	nd	nd
	J2003	13	6	8	10	tr	–	tr	63	33	–	67	tr	9	78	13	–	–	44	26	18

Qtz quartz, Kfs potassium feldspar, Pl plagioclase, Cal calcite, Dol dolomite, Gp gypsum, Hem hematite, Phy phyllosilicates, Ill illite, Sm smectite, Kln kaolinite, Chl chlorite, I/S illite/smectite mixed layer, tr traces. Wl liquid limit, Wp plastic limit, Ip plasticity index, nd not determined

^a Contains flocculant

present in all the wastes, but may reach maximum values of 38 and 14%, respectively. Dolomite and hematite are only identified as traces, in a small group of wastes.

The averages of quartz and feldspars are rather similar, about 20%, and remain quite uniform in all the terrace systems (Table 5). Only the Intermediate terraces, at the middle course, are depleted in feldspars (13%). Waste found in the middle course is richer in phyllosilicates (above 60%) than that from the lower course (about 50%). Most of waste is produced in the lower course, so that phyllosilicates average 53% if the whole Jarama river waste is considered.

As shown in Fig. 2, waste found in the middle course is carbonate-free. In this sector of the river, only the J20 pit, washing Higher terraces deposits, generates waste containing calcite (10–20%). Nevertheless, waste collected in the lower course contain appreciable amounts of carbonate, where calcite reach up to 38% of the bulk. Gypsum is rarely a component of the wastes and reaches values above 5% only in the gravel pit (J01).

Composition of sand and gravel fractions

The volume of gravel-size particles (>2 mm) in the waste is low, rarely more than 2%. This means that the

Table 4 Mineralogical composition and plasticity values of sand and gravel washing wastes from Jarama river Lower course

		Bulk Mineralogy (%)							2–20 μm (%)				<2 μm (%)				Plasticity (%)				
		Qtz	Kfs	Pl	Cal	Dol	Gp	Hem	Phy	Ill	Sm	Kln	Chl	Ill	Sm	Kln	Chl	I/S	Wl	Wp	Ip
Lower + Intermediate terrace deposits	J0801	43	10	13	13	–	–	–	21	62	tr	38	tr	21	62	17	tr	tr	nd	nd	nd
	J0802	17	5	5	17	–	–	–	56	60	tr	40	tr	23	53	24	tr	tr	66	33	33
	J0803	20	8	7	18	–	–	–	47	56	tr	44	tr	30	46	24	–	–	49	30	19
	J0804	41	7	8	9	tr	tr	–	35	64	tr	36	tr	23	61	16	tr	–	31	23	8
	J0805	21	5	5	tr	tr	tr	tr	69	66	–	34	tr	26	54	20	tr	–	32	23	9
	J0602	11	8	14	10	–	–	–	57	60	–	40	tr	21	58	21	–	–	45	25	20
	J0603	7	6	5	tr	–	–	–	82	55	–	45	tr	22	55	23	–	–	60	29	31
	J0604	12	5	8	5	–	–	–	70	54	tr	46	tr	24	54	22	tr	tr	63	28	35
	J0605	7	5	5	5	–	–	–	78	55	tr	45	tr	22	60	18	tr	tr	64	30	34
	J0402 ^a	11	5	5	6	–	–	–	73	63	–	37	tr	17	68	15	tr	tr	47	30	17
	J0403 ^a	10	5	6	4	–	–	–	75	59	–	41	tr	17	73	10	tr	tr	49	28	21
	J0404	10	4	6	17	–	–	–	63	64	tr	36	tr	19	64	17	tr	tr	35	22	13
	J0501	32	32	11	8	–	–	–	17	62	–	38	tr	26	45	29	–	tr	30	25	5
	J0502	25	17	19	tr	–	–	–	39	59	–	41	tr	13	68	19	–	–	31	27	4
	J0503	15	11	35	tr	tr	–	–	39	61	tr	39	tr	18	58	24	tr	–	26	22	4
	J0504	42	9	16	5	tr	–	–	28	60	–	40	tr	16	68	16	–	tr	28	25	3
	J2201	22	22	20	9	–	–	–	27	59	–	41	tr	18	66	16	tr	–	nd	nd	nd
	J2202	18	12	7	7	tr	tr	tr	56	66	–	34	tr	19	66	15	tr	–	44	25	19
	J2203	8	7	10	5	tr	tr	tr	70	66	–	34	tr	31	52	17	tr	tr	45	22	23
	J2204	21	6	12	8	–	–	–	53	70	tr	30	tr	21	65	14	–	–	44	24	20
	J2205	15	6	10	8	tr	–	–	61	68	tr	32	tr	23	62	15	tr	tr	47	26	21
	J0701	16	9	9	8	–	–	–	58	60	–	40	tr	14	71	15	–	–	28	21	7
	J0702	38	23	12	12	–	–	–	15	61	–	39	tr	25	45	30	tr	tr	26	21	5
	J0703	22	19	22	10	tr	–	–	27	60	–	40	tr	19	62	19	–	–	27	20	7
	J0704	24	13	24	14	–	–	–	25	57	–	43	tr	30	52	18	–	–	25	20	5
	J2301	8	5	7	26	tr	–	tr	54	52	–	48	tr	14	71	15	–	–	40	26	14
	J2302	6	6	9	25	tr	–	tr	54	52	–	48	tr	21	58	21	–	–	39	26	13
	J2304	15	21	20	25	tr	–	–	19	46	–	54	tr	12	70	18	tr	tr	nd	nd	nd
	J0301	19	14	15	11	–	–	–	41	59	tr	41	tr	29	50	21	tr	tr	nd	nd	nd
	J0302	13	18	11	4	–	–	–	54	60	tr	40	tr	25	56	19	–	–	26	21	5
	J0303	14	13	14	10	–	–	tr	49	58	–	42	tr	30	53	17	tr	tr	31	22	9
	J0304	18	21	16	12	–	–	tr	33	61	–	39	tr	32	58	10	–	tr	25	20	5
	J1301	12	5	6	14	–	–	–	63	62	–	38	tr	20	57	23	–	–	58	27	31
	J1304	15	9	12	15	–	–	–	49	61	–	39	tr	17	58	25	–	tr	31	21	10
	J1305	14	8	11	12	–	–	–	55	60	–	40	tr	22	55	23	tr	tr	39	25	14
	J0201	28	11	21	7	–	–	–	33	59	–	41	tr	23	52	25	tr	tr	28	23	5
	J0202	13	7	10	5	–	–	–	65	62	–	38	tr	19	58	23	–	–	41	27	14
	J0203	11	11	6	8	–	–	–	64	63	–	37	tr	21	59	20	–	–	36	22	14
	J0204	22	17	14	9	–	–	–	38	66	tr	34	tr	20	55	25	–	–	26	22	4
	J0205	9	8	tr	8	–	–	–	75	62	tr	38	tr	23	58	19	–	–	49	28	21
	J0206	6	8	6	9	–	–	–	71	60	tr	40	tr	21	62	17	–	–	48	29	19
	J1201	20	5	7	19	tr	–	–	49	60	–	40	tr	15	65	20	–	–	65	30	35
	J1202	26	tr	8	7	tr	–	–	59	62	–	38	tr	15	70	15	tr	tr	42	25	17
	J1203	32	7	7	9	tr	–	–	45	65	–	35	tr	16	66	18	–	–	38	23	15
	J1204	47	5	5	5	–	–	–	38	66	–	34	tr	22	56	22	tr	–	27	19	8
J1205	42	8	5	8	tr	–	–	37	60	tr	40	tr	19	58	23	tr	–	27	20	7	
J0901	11	13	13	11	–	tr	tr	52	65	–	35	tr	22	58	20	tr	tr	28	23	5	
J0902	18	8	17	11	–	tr	tr	46	66	–	34	tr	21	59	20	tr	tr	28	21	7	
J0903	14	14	11	7	–	–	tr	54	63	–	37	tr	15	68	17	tr	tr	50	27	23	
J0904	12	12	14	12	–	tr	tr	50	60	tr	40	tr	22	64	14	–	tr	52	26	26	
J0101	16	20	14	14	–	14	–	22	69	–	31	tr	15	72	13	–	–	25	20	5	
J0102	11	5	7	21	tr	12	–	44	65	–	35	tr	19	65	16	–	tr	33	23	10	
J0104	14	17	10	15	tr	9	–	35	63	–	37	tr	18	70	12	–	tr	35	24	11	
J2101	16	12	6	21	–	–	–	45	60	tr	40	tr	22	62	16	–	–	28	20	8	
J2102	7	5	8	27	tr	tr	tr	53	54	tr	46	tr	26	64	10	tr	tr	67	28	39	
J2103	24	8	13	14	tr	–	–	41	64	tr	36	tr	22	61	17	tr	tr	29	26	3	
J2104	16	9	8	22	tr	–	–	45	66	–	34	tr	23	58	19	–	tr	32	23	9	
J2105	19	8	7	18	tr	–	–	48	58	–	42	tr	24	61	15	tr	tr	33	22	11	

Table 4 continued

	Bulk Mineralogy (%)								2–20 μm (%)				<2 μm (%)				Plasticity (%)			
	Qtz	Kfs	Pl	Cal	Dol	Gp	Hem	Phy	Ill	Sm	Kln	Chl	Ill	Sm	Kln	Chl	I/S	Wl	Wp	Ip
J2106	21	17	14	13	tr	–	–	35	59	–	41	tr	32	48	20	–	tr	32	20	12
J1101	6	5	6	38	–	–	–	45	65	–	35	tr	26	50	24	tr	–	63	33	30
J1102	5	5	5	35	–	–	–	50	60	–	40	tr	23	55	22	tr	–	70	28	42
J1103	18	17	12	19	–	–	–	34	63	–	37	tr	25	48	27	tr	tr	31	19	12

Qtz quartz, Kfs potassium feldspar, Pl plagioclase, Cal calcite, Dol dolomite, Gp gypsum, Hem hematite, Phy phyllosilicates, Ill illite, Sm smectite, Kln kaolinite, Chl chlorite, I/S illite/smectite mixed layer, tr traces. Wl liquid limit, Wp plastic limit, Ip plasticity index, nd not determined

^a Contains flocculant

conglomerate washing process is quite efficient, recovering practically all the saleable coarse aggregates. In the middle course, these gravel particles are composed of quartz (single crystals and polycrystalline grains), potassium feldspar (pink and white, partially or unaltered crystals), Fe-hydroxides and lithic fragments, including quartzite, fine-grained schist and slate/phyllite. Small differences are recognized in the wastes from the lower course; only the presence of chert (absent from the waste at the middle course) and a lesser proportion of schist and slate lithic fragments. Plant matter, such as stems, leaves, roots, shrubs, etc., is also frequently found in both courses, and can represent the total fraction blocked in the 2 mm sieve.

The coarser sands (0.4–2 mm) are quartz, feldspar, lithic fragments (quartzite, and minor slate/phyllite) and fine-grained schist. Muscovite mica crystals are very frequent, with characteristic sub-circular to sub-hexagonal sections and dimensions greater than 1mm. Additionally, some isolated carbonate fragments were recovered from the wastes from lower course, and only in the waste J2002, from the middle course. The fraction between 0.06 and 0.4 mm is composed of quartz, potassium feldspar, muscovite, altered biotite mica, and minor lithic fragments, mainly chlorite-schist. Other minor components, such as sillimanite, staurolite and garnet are found in this fraction.

Composition of the 2–20 μm fraction

Because of the abundance of phyllosilicates in the wastes studied, the analyses of silt and clay ranges is essential. The 2–20 μm assemblages are composed of illite (27–70%) and kaolinite (30–73%), with traces of chlorite and smectite (Table 5).

Placing these compositional results along the Jarama river, and considering every waste (Fig. 3), we emphasize that illite amounts are reasonably regular, and typically bigger than kaolinite ones. This path is

reversed only in a number of wastes collected from the middle course, particularly pits J18 and J19 (Intermediate terraces) and J20 (Higher terraces), where the kaolinite content surpasses 65% of the 2–20 μm fraction.

Composition of the <2 μm fraction

The phyllosilicates included in the clay fraction are composed of smectite (45–92%), kaolinite (5–36%), illite (5–32%), and minor chlorite and mixed layer illite/smectite (Tables 3, 4). The comparison between wastes is shown in Fig. 4, where they are plotted by location. Smectite-group minerals are widely present in the clay fraction, and are normally the main phases of all wastes. This group of clay minerals is especially relevant in the wastes collected in the middle course, reaching values above 75% in J15 and J10 gravel pits. There is a reasonably homogeneous relation between the other two major minerals of the clay fraction, where kaolinite/illite ratio is about unity on every waste. As shown in the 2–20 μm range, waste from J18 and J19 pits is rich in kaolinite, whose kaolinite/illite ratios are bigger than 3.5, and chlorite-group minerals are absent.

Plastic behaviour

The Atterberg limits delineating the plasticity of the wastes studied are listed in Tables 3 and 4, and plotted in the Bain diagram, grouped by their location (Fig. 5). Most of wastes exhibit a suitable (“A” area) plastic behaviour for their direct applications in brickmaking. The plastic limit varies between 20 and 35%, and increases as the plasticity index increases. Wastes from different terrace systems show a remarkable overlapping, so that it is impossible to divide them solely according to their plastic behaviour. This homogeneity is strongly positive for their industrial application.

Table 5 Mineralogical compositions (%) of wastes from Jarama river pits, considering the river course and mined terrace level

Terraces		Middle course						Lower course		Total Jarama	
		Higher (<i>n</i> = 3)		Intermed. (<i>n</i> = 7)		Lower+ (<i>n</i> = 25)		(<i>n</i> = 62)		(<i>n</i> = 97)	
		Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
Bulk	Quartz	15	7–25	19	5–26	18	6–48	18	5–48	18	5–48
	Feldspars	21	7–40	13	8–22	21	8–44	21	8–46	20	8–46
	Carbonates	13	10–20	tr		tr		12	tr–38	8	tr–38
	Phy.	51	15–76	68	52–85	61	36–85	48	15–82	53	15–85
2–20 μm	Illite	43	37–59	28	27–30	52	32–61	62	46–70	56	27–70
	Smectite	tr		tr		tr		tr		tr	
	Kaolinite	57	41–67	72	70–73	48	39–68	38	30–54	44	30–73
	Chlorite	tr		–		tr		tr		tr	
<2 μm	Illite	12	9–15	11	9–13	11	5–21	21	12–32	18	5–32
	Smectite	72	63–78	58	52–65	73	48–92	60	45–73	63	45–92
	Kaolinite	16	13–22	31	25–36	16	5–24	19	10–30	19	5–36
	Chlorite	tr		–		tr		tr		tr	
	I/S	tr		tr		tr		tr		tr	

Phy phyllosilicates, *I/S* illite/smectite mixed layer, *tr* traces, *Av.* average, *n* number of wastes, *Intermed.* Intermediate terrace system, +include the actual flood plain

Discussion

The natural characteristics of the Jarama river deposits make the study area the main target for aggregate production. The concentration of mining companies in this sector is attributable to remarkable features:

- The Jarama river conglomerates are characterized by high percentages of hard pebbles (>90% of quartz and quartzite), being well known also by elevated roundness indices (Pérez-González and Brell 1969; Pérez-González 1971).
- The proximity of Madrid city and neighbouring metropolitan areas—the highest aggregate customers—enhance the strategic location of the studied fluvial deposits, noticeably reducing the transport cost.
- The existence of a relatively wide valley (~4–5 km) where large territories can be exploited, and the abundance of water for the washing process.
- The Jarama river reserves exceed 1.4×10^9 ton, representing roughly four-fifths of the Madrid province conglomerate reserves (AMA 1990), and guarantee long-term future supply.

These features are especially important in the lower course, where gravel pits are located on thick sequences of fluvial deposits. Here about three quarters of the Jarama river washing waste are generated (Blanco García 2004).

According to Vaudour (1979), the extraordinary abundance of well-rounded, quartz and quartzite pebbles in the Jarama river terraces is caused by the

continuous recycling of the sedimentary materials, eroded from the Central System. These include Pliocene “raña” conglomerates, Miocene proximal conglomerates, arkose fans, etc., and even older terrace levels that have been reworked, making difficult their sedimentological study (Asensio Amor and Vaudour 1967). The composition of these sediments reflects the petrology of the rocks and soils eroded by the Jarama fluvial system. Sand and gravel fractions of the studied wastes concentrate quartz, feldspars and micas and, in smaller proportions, rock fragments, such as quartzite, slate, schist or granite. In this work, the study of a representative number of wastes, which concentrate the silty-clay fraction of the Jarama river terraces, allow discussion of whether the homogeneity found in previous works in coarser fractions is also applicable to the fine fractions, thus it represents a new perspective. The relative proportion of the main components (quartz, feldspars and phyllosilicates), does not allow clear waste distinction along Jarama river. However, major differences are noticed in the middle and lower courses, depending on carbonate and gypsum contents (Fig. 2), as discussed below.

Origin of the carbonates in the sand and gravel washing waste

A clear distinction between carbonate-bearing and free carbonate wastes is essential for their ceramic applications, since these components influence significantly the properties of ceramic products. Wastes from the

Fig. 2 Bulk mineralogy of the wastes studied, grouped by pits, represented on a schematic map and cross-sections of the Jarama river terrace systems

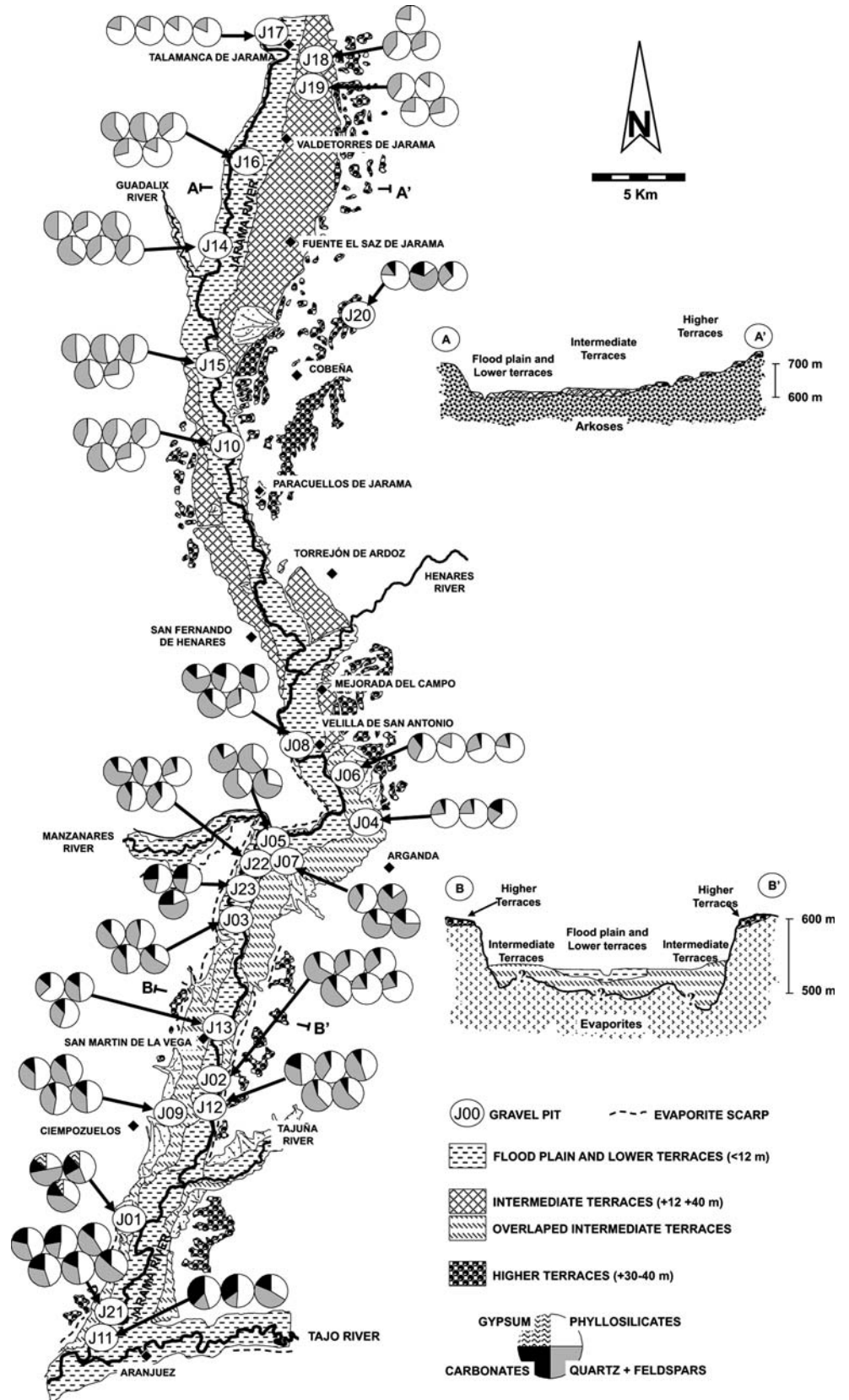


Fig. 3 Mineralogy of the wastes studied (fraction 2–20 μm), grouped by pits, represented on a schematic map and cross-sections of the Jarama river terrace systems

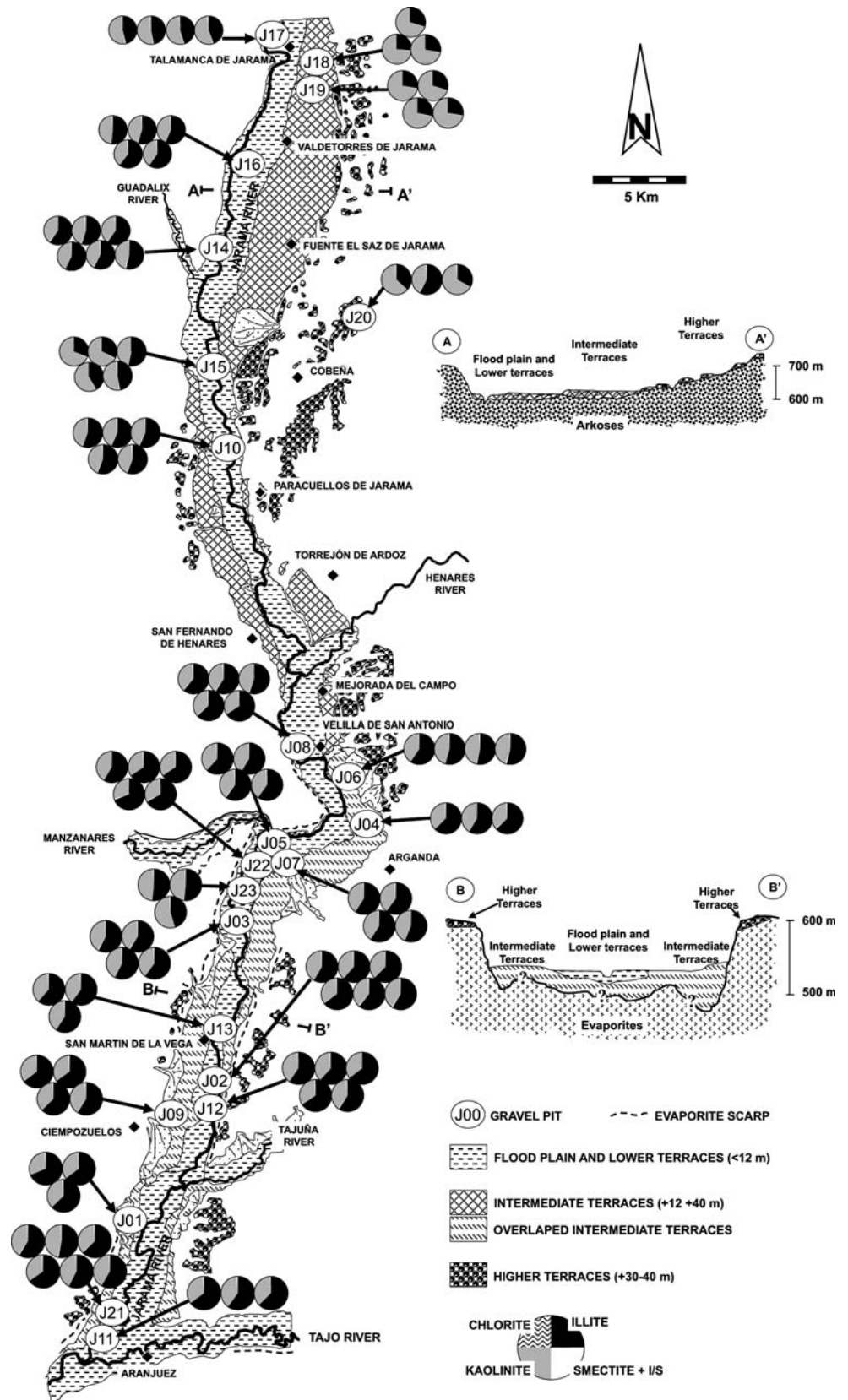
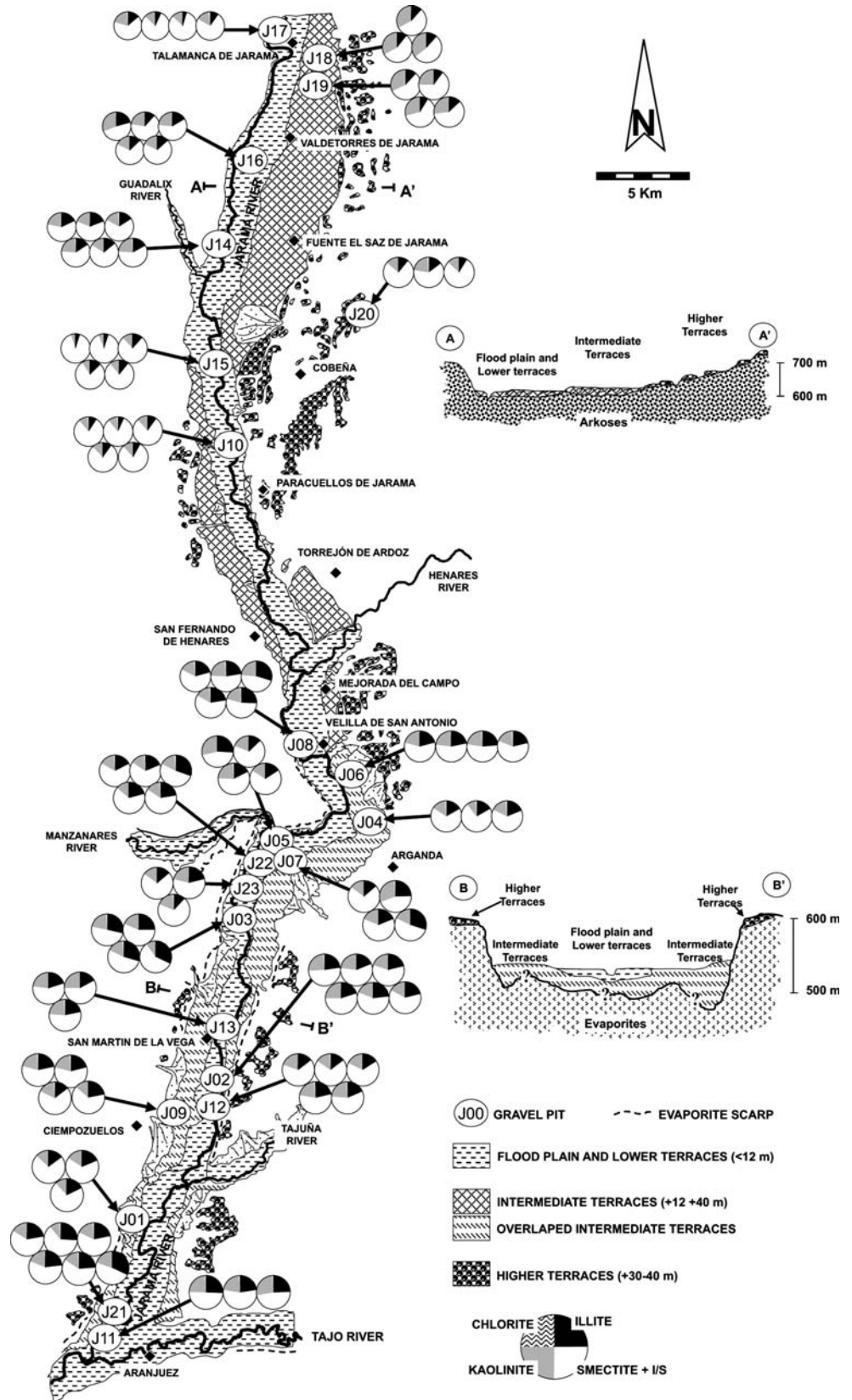


Fig. 4 Mineralogy of the wastes studied (fraction <math><2\ \mu\text{m}</math>), grouped by pits, represented on a schematic map and cross-sections of the Jarama river terrace systems



middle course are commonly carbonate free, while wastes generated in the lower course contain appreciable amounts of calcite. Additionally, carbonates concentrate in the silty fraction, and the sand fraction rarely contains calcite. These carbonates can originate from two processes: 1-Erosion and transport of carbonate particles; 2-Precipitation of carbonates in sand and gravel porosity.

1- Erosion and transport of carbonate particles

The Jarama river catchment area is characterized by the absence of carbonated rock, with minor Cretaceous and Paleogene carbonate outcrops, in the north of the studied zone (Fig. 1). On the contrary, the catchment area of the Henares and Tajuña rivers, the most important tributaries of the Jarama in the lower course, is mainly composed of Mesozoic marine carbonates (Iberian System and Altomira Range) and Cenozoic continental carbonates (“Páramo” limestone). Therefore, the presence of carbonates in the Jarama river lower course can be due to physico-chemical weathering of carbonate pebbles, present along the Henares and Tajuña terraces. In this context, Asensio Amor and Vaudour (1967) and Silva et al. (1988) underline that Jarama river terraces show a notorious compositional homogeneity in the gravels, only locally modified by the contributions of Henares and Tajuña tributaries, adding carbonated pebbles to the Jarama terraces. Nevertheless, this study shows that carbonates are present in all wastes generated in the lower course, and not exclusively in the areas located near the joints of Henares and Tajuña river. This fact, linked to the carbonate concentration in the finest fractions, points to another essential process that globally distributes these minerals in all the terraces of the Jarama river lower course. Probably, this process is the direct precipitation of calcite from saturated underground waters.

2-Precipitation of carbonates in sand and gravel porosity

The precipitation of calcite in the Jarama river terraces takes place by reaction of dissolved HCO_3^- and Ca^{2+} in groundwater. According to Bustos Aragón et al. (1989), the confluence with the Henares river produces an important change in the chemistry of the Jarama river underground water. Martínez (1996) confirms the data of Gómez (1983) after studying underground waters in the Jarama valley, downstream of the confluence with the Henares river.

They establish clear zonation patterns in the underground water mineralization, at the Jarama river lower course. With the exception of bicarbonate, every analysed parameter (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-}) diminishes in the direction of the groundwater flow. Thus, approaching the Jarama river thalweg, where the water regeneration is greater, the underground flow increases. The greater amount of bicarbonate in dissolution, close to the river thalweg, means that less carbonate is precipitated in the sand and gravel porosity. Thus, in the lower Jarama river course, the calcite neoformation process is much more important than physical weathering of existing carbonate particles, although the dissolution of this type of pebble and, therefore, the increase of ions in solution, are strongly facilitated by a previous fragmentation of eroded calcareous grains.

Calcite significantly increases above 15% in the waste downstream of the confluence of the Tajuña river and Jarama river (Fig. 2). Here, the left-bank Jarama terraces have a strong precipitation of carbonate, being considered a barren resource (PORN 1999). High hardness underground water from the Tajuña river, has the greater contents of Ca^{2+} , CO_3^{2-} and HCO_3^- of all the fluvial systems in the studied area (Bustos Aragón et al. 1989). These dissolved ions precipitate as calcite in the porosity of Jarama conglomerates and cement them firmly.

Pits J11 and J21, giving the highest calcite contents, do not concentrate carbonate in the coarser fraction, pointing to calcite neoformation. The settling ponds of both pits develop algae or other unidentified communities of organisms, forming green “carpets” on the wastes, especially in the shallow, well-illuminated zones. These organisms can also accelerate the precipitation of fine carbonates, fixing CO_2 by means of photosynthetic processes.

As shown in Fig. 2, three wastes from the middle course contain significant amounts of carbonate (10–20%). They were sampled in the J20 gravel pit, which is the only one mining Higher terraces. These conglomerates, carbonate-bearing deposits, are especially abundant as isolated patches. They are the oldest terraces in the Valdetorres de Jarama-Paracuellos de Jarama sector, and thick calcrete-type carbonate deposits are developed on them (Asensio Amor and Vaudour 1967; López and Pedraza 1976; Lázaro Ochaíta and Asensio Amor 1978; Vaudour 1979; Alonso and Garzón 1994; Roquero et al. 1996). Therefore, carbonate-bearing waste is only found in the Jarama river middle course if the Higher terraces are washed for aggregate.

Origin of gypsum in the sand and gravel washing waste

Gypsum is exclusively present in wastes generated in the lower course, since the substrate of these Quaternary fluvial deposits is the Miocene Evaporitic Unit, composed of gypsum, clays, calco-sodic sulphates and carbonates. Gypsum is detected in 8% of those wastes, and only as traces, but in the J01 pit it can constitute more than 10% of waste. Here, the J01 pit is located next to Miocene gypsum-bearing escarpments, and the alluvial cones, that erode the scarps, interdigitate and onlap the dug fluvial deposits, contributing gypsum fragments from sand to boulder size. Thus, gypsum is significantly present in the waste only if the benefited terraces are located near the Miocene escarpments.

The presence of gypsum is especially important for the ceramic application of these wastes since sulphate impurities in a ceramic raw material can dissolve during the wetting process and reprecipitate during drying, increasing the tendency for efflorescence to occur. During firing they also burn away and important amounts of SO₂ and SO₃ can be emitted into the atmosphere. Therefore, a “risk” of gypsum presence exists only if the open pit is located in the lower course, and at the foot of a Miocene evaporite-bearing scarp.

Origin of silt and clay associations in the sand and gravel washing waste

Rivers do most of the erosional work of landscape shaping. The transport and deposition of sediments produced by eroding rocks and soils are important parts of the cycle that forms fluvial terraces. Evidently, the composition of these fluvial sediments and sedimentary rocks will be strongly influenced by the nature of weathering in the source area of the sediment. As shown in Fig. 2, wastes generated by washing Jarama river terraces are rich in phyllosilicates. These phyllosilicates, that concentrate in the silt and clay fractions, are composed of smectite, kaolinite, illite, and traces of chlorite and illite/smectite mixed layer (Figs. 3, 4). Chamley (1989) suggests a detrital origin of the argillaceous Quaternary fluvial sediments primarily, since there is a good correspondence between the mineralogy of the clays of the fluvial deposits, and the bedrock and soils put under erosion. An important alteration of the bedrock takes place specifically during soil formation. The importance of clays formed in soils is relevant to the clay mineralogy of the related fluvial courses since most eroded sediment is not derived directly from the bedrock but from soils formed on it. Thus, the

mineralogy of clays eroded from a source area and drained by a fluvial system, is controlled by the mineralogy of the parent bedrock, and the mineralogy of soils developed on the bedrock (Eslinger and Peaver 1988). In addition to the variation in physical and chemical conditions within the weathering profile, it should be borne in mind that the overall nature of the soil, and to a large extent that of the saprolite and weathered rock, will depend upon the five classical factors identified by Jenny (1941), namely climate, topographic position (influencing drainage), parent material, time and biota.

Weathering of rocks and soil is the primary way that clays and clay minerals form at the Earth's surface today (Foley 1999). The weathering process involves physical disaggregation and chemical decomposition that change original minerals to clay minerals. In the Jarama river catchment area, phyllosilicates are scarce in the granitic rocks of the Central System. The modal proportions are about 10 and 4%, for biotite—partially altered to chlorite—and muscovite, respectively (Villaseca and Herreros 1996). A large component of soils formed by weathering of granites may consist of metastable muscovite, biotite and chlorite, that are altered progressively to clay minerals. The hydrolysis of potassium feldspar and plagioclase, abundants in the rocks of the Central System, gave rise to important amounts of kaolinite and smectite clays in the Jarama deposits. It has often been asserted that illite is a common weathering product of feldspar in soils, but as yet there seems to be little unequivocal evidence to support this contention (Wilson 2004). Complex mixed-layer clay minerals (such as illite-smectites) are abundant in clay assemblages that develop from mica-bearing precursor rocks (Foley 1999). Common metamorphic bedrock lithologies throughout the Central system include slate, schist, gneiss and quartzite, which contain abundant muscovite, biotite, chlorite and feldspar (Fúster et al. 1974; López et al. 1975; Aparicio and Galán 1980; Arribas et al. 2000). These minerals alter during weathering to clay minerals such as illite, smectite, vermiculite and kaolinite (Grim 1968; Bloom 1969; Velde 1985; Blatt 1992), all of which were probably produced during the long period of weathering required to develop thick soil profiles. During subsequent uplift and erosion in the early to middle Pleistocene, the clays may have been transported and deposited as alloctenic minerals with other sediments to form the Jarama terraces.

Other processes than detrital origin of the silty-clay associations can be related to the different phenomena that occur in the fluvial environments. Johnsson and Meade (1990), and Morton and Hallsworth (1999) have

shown that further weathering of sediment occurs during periods of alluvial storage on floodplains, which may have resulted in additional clay minerals being produced, if a relative long period exists. In addition, the seepage of muddy water through gravel alluvium may result in the deposition of mechanically infiltrated clays (Moraes and De Ros 1990). During floods, the Jarama river floodplain would have been repeatedly inundated with muddy water that enhanced the formation of mechanically infiltrated clays. Once deposited, allogenic and mechanically infiltrated clay minerals may recrystallize (Lowey 2001). This diagenetic process mainly involves a change in size (usually an increase) or shape of mineral crystals, without significant changes in composition (Boggs 1987). Other allogenic minerals (such as feldspar and mica) deposited with the Jarama river conglomerates may undergo diagenetic alteration to authigenic clay minerals (i.e., kaolinite, illite and smectite), similar to the weathering process described previously.

Climate is considered the most significant long-term control of weathering, and therefore the type of clay minerals produced during weathering is thought to reflect the climate at the time of formation (Grim 1968; Easterbrook 1993). Generally, kaolinite is characteristic of more temperate and humid climates, whereas smectite is characteristic of warm to subhumid climates (Berner 1971; Foscolos et al. 1977). Temperate climates, as in the study zone, allow only partial dealcalinization and produce a degradation of the phyllosilicates: primary phases are first exfoliated by hydrolysis, giving way to “open” structures (Chamley 1989). Under these conditions, chlorite is usually less resistant to hydrolysis than illite, which is why it is less abundant in the Jarama river terraces.

In temperate zones, clay assemblages commonly reflect an increase in weathering effects in old paleosols, compared to young ones (e.g., Allimen and Calliere 1964a, b; Icole 1973; Bornand 1978; Mary and Grenèche 1986). For instance, the Villafranchian (late Pliocene–early Pleistocene) sediments, founded in the peri-Mediterranean range, including the source area of the studied zone, are often blanketed by rubefied soils rich in kaolinite (Vaudour 1983), contrary to what occurs with middle to late Pleistocene sediments (Chamley 1989). Such a change is partly due to the severe hydrolytic conditions during the late Pliocene and early Pleistocene, that caused the formation of kaolinite- and smectite-rich sediments by washing Na⁺ and K⁺ from illite and feldspar (Vicente et al. 1987; Martínez Lope et al. 1995). As shown in Figs. 3 and 4, kaolinite-rich waste, both in the clay (<2 µm) and fine-medium (2–20 µm) silt fraction, is found in the

Intermediate terrace system, at the middle course (gravel pits J18 and J19). The location of these pits is directly related to the La Galga stream, a small Jarama river tributary, that dissects the Villafranchian paleosols, enriched in kaolinite (Gallardo et al. 1987) and with total absence of chlorite. Additionally, the lower feldspar content in these Intermediate terraces (Table 5) confirms a long period of weathering, where the hydrolysis of feldspars generates typically an increase in the kaolinite amount.

Waste collected downstream from the Guadalix river mouth (pits J15 and J10), is rich in smectite (Fig. 3), especially in the J15 pit, that is located in the confluence of the Viñuelas stream and Jarama river. The Viñuelas stream receives waters from Valdela-masa and Los Canos stream, entirely draining the Miocene arkosic substrate. Clay minerals included in these arkoses are mainly composed of smectite with smaller amounts of illite and kaolinite (e.g. Alonso Zarza et al. 1986; Domínguez Díaz 1994; Domínguez Díaz et al. 1996). Thus, the erosion of smectite-rich arkosic substrate increases the smectite amount in the clay fraction of waste in this sector of the river.

Downstream from the Henares river junction, clay assemblages are depleted in the smectite (Fig. 4), increasing the illite amount over the kaolinite. Along the lower course, the evaporite clay-rich substrate is characterized by illite and illite–kaolinite clay assemblages (García del Cura 1979; García Romero 1988; García Santiago 1988). Therefore, the evaporite unit could contribute to the Jarama terraces certain amounts of illite, and less kaolinite, when the river incision took place, and by the lateral alluvial fans that carve the Miocene scarps, as discussed above for the gypsum.

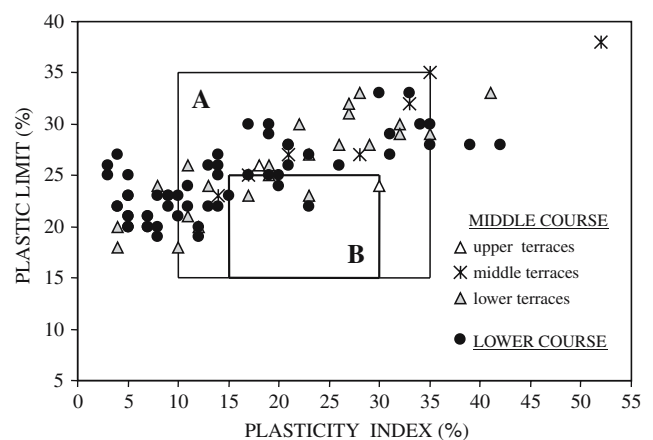


Fig. 5 Plastic behaviour of the studied wastes, plotted in the Bain diagram. “A” and “B” fields identify “Suitable” and “Optimum” compositions for extrusion, respectively

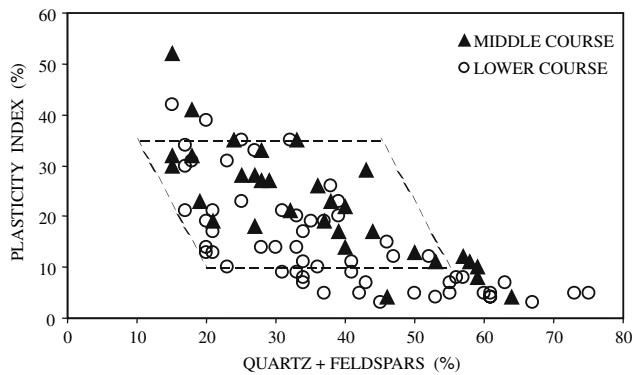


Fig. 6 Correlation between plasticity index and (quartz + feldspars) on every waste. The *dashed line* groups wastes suitable for direct extrusion

Plastic behaviour: an approach to the technological application of the waste

In view of the large volume of waste generated every year in the studied area, and its silty-clay composition, a potential use could be in the heavy clay industry, due to the remarkable consumption of silty-clay raw materials in this industry. Ceramic bodies are produced by accurately mixing variable plasticity raw materials, because of the extrusion shaping requirements. This study shows that more than two-thirds of the Jarama river sand and gravel washing wastes are similar to the raw materials used in brickmaking (Stein 1982; Fabbri and Dondi 1995a, b; Stark 2000; Hatzl and Gehlken 2001), thus making possible an accurate blend for extrusion. Indeed, most of the wastes are suitable for direct extrusion (Fig. 5), so that ceramic bodies can be made using only Jarama river wastes. This facilitates their industrial application, because of the homogeneity requirements of a ceramic raw material. A group of wastes is characterized by low plastic limits, and there is a correlation between plasticity index and bulk mineralogy (quartz + feldspars) (Fig. 6). Waste rich in quartz and feldspar shows a low plasticity index, while waste poor in those components show higher Plasticity Indices. This approach can be used to improve the estimate for shaping, and only for the maximum limit of quartz + feldspars: waste containing more than 55% of quartz + feldspars can only be used as a tempering additive, improving the plastic behaviour of raw materials with high plastic limits.

Conclusions

The sand and gravel washing waste generated in the middle and lower Jarama river course is composed of

quartz, potassium feldspar, plagioclase and phyllosilicates. The main variations in this mineralogical assemblage are conditioned by the location of the mined terrace, essentially affecting the presence of carbonates and gypsum:

- Waste generated by washing conglomerates from the Jarama river lower course contain also calcite, averaging 12%.
- Waste generated by washing conglomerates from the middle course (Intermediate + Lower terraces) do not contain carbonates or just as traces if they do. Nevertheless, waste found in the middle course is rich in carbonates only if it comes from the washing of the Higher terraces.
- Gypsum is present in waste found in the lower course, where it is scarcely detected. Only gravel pits, located at the foot of valley scarps, can produce significant gypsum-bearing waste, due to the “contamination” of the fluvial conglomerates by the alluvial fans, that erode the Miocene gypsum-bearing valley sides.

The study of the silt and clay fraction shows a great homogeneity in compositions, and some variations in their proportion are noted:

- The assemblages found in the 2–20 μm fractions are composed of illite, kaolinite, and traces of chlorite and smectite. Kaolinite is especially abundant in the Intermediate terraces, at the middle course, due to the direct contribution of the La Galga stream that erode thick rubefied Paleosols, rich in this phyllosilicate.
- Waste is composed of smectite-, illite-, kaolinite-, and traces of illite/smectite mixed layer- and chlorite-clays. As detected in the silt fraction, kaolinite rich waste is generated from the Intermediate terraces, at the middle course. A certain increase in the illite proportion is detected in the lower course, reflecting the interaction of the fluvial system with the Tertiary bedrock.
- Most waste generated in the Jarama river middle and lower course shows a suitable plastic behaviour for direct application in the heavy clay industry. Quartz- and feldspar-rich waste can be applied as tempering additives, improving the workability of high-plasticity raw materials. Nevertheless, further studies are necessary to certainly understand the potential applicability of Jarama river sand and gravel washing waste in the heavy clay industry.

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