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SOURCE-AREAS OF SEDIMENTS IN BRAIDED RIVERS: THE EXAMPLE OF RIVER OJA (IBERIAN SYSTEM, SPAIN)[1]

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SUMMARY

The authors indentify the source-areas of sediments in a braided river. Studying the slope dynamics and the gravel-size along the channel, they conclude that the mass movements and the active headwaters of ravines are the most important areas of sediment production. In this sense, some tributaries into the Sierra de la Demanda and the basin border conglomerates behave as responsible sectors of the origin and increase of braiding.

RESUMEN

Los autores identifican las áreas fuente de sedimentos en un río trenzado. A partir del estudio de la dinámica de vertientes y del tamaño de los cantos a lo largo del cauce, concluyen que los movimientos en masa y las cabeceras activas de barrancos son las áreas productoras de sedimentos más importantes. En este sentido, algunos afluentes dentro de la Sierra de la Demanda y los conglomerados de borde de cuenca se comportan como los sectores responsables del origen e incremento del anastomosamiento.

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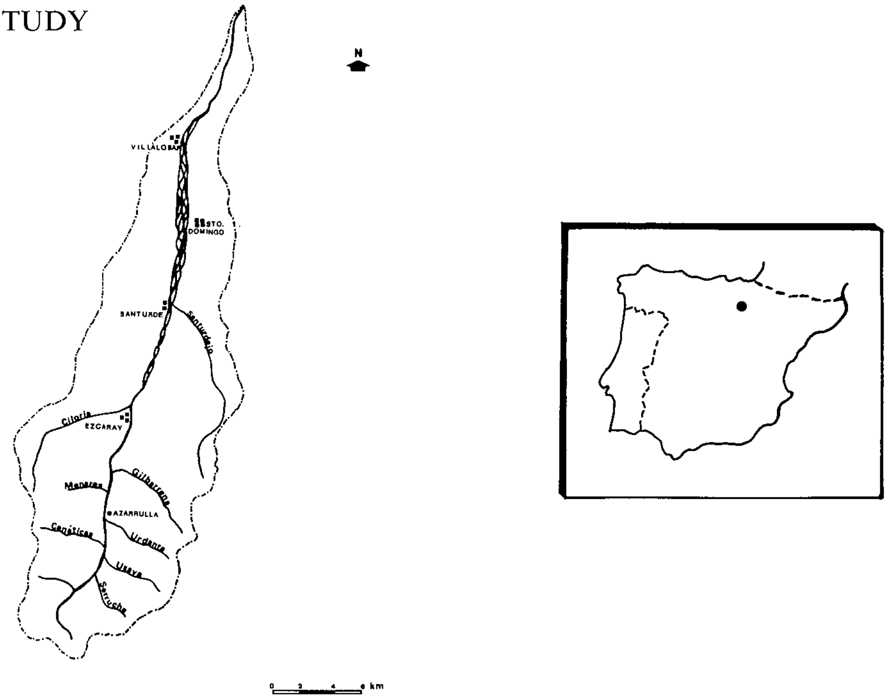
Braided rivers have been described in a great range of environments. They are defined by their large relation width/depth, by the dominance of coarse materials in the sediment load and by their high energy. The consequence is a channel in wich many secondary channels are interlaced, changing frequently their position during floods; such channels originate islands between them that alter their form and dimension at short-term. LEOPOLD and WOLMAN (1957), KRIGSTROM (1962) and FAHNESTOCK (1963) and others point out that the basic conditions for spreading of braided channels are the torrentiality of river regime and the existence of contrasts between areas with strong slopes and areas with low energy, that is, quick decrease of transport capacity. LEOPOLD, WOLMAN and MILLER (1964), GREGORY and WALLING (1976), SCHUMM (1977) and RICHARDS (1982) argue that the basin must be affected by a very active slope dynamics: Torrents with functional headwaters, mass movements of great spread and high drainage density are the decissive factors in this sense. The sediments arriving the channel must have a great proportion of coarse materials, since the fine ones are easily displaced, even in low-water periods; such sediments must reach the river instantaneously, to avoid a quick displacement downstream.

Then, a braided river is characterized obviously by the importance of coarse sediment load. For this reason this channel pattern is frequent in arid and semiarid climates, and in the proglacial fronts, though they can also be located in mountainous areas with seasonaly weathering. This last case is that of the River Oja basin, in which we attempt to analyze the relations between the evolution of braiding and slope dynamics, with location of sediments source-areas. So we shall study the more outstanding geomorphological features and the evolution of the gravel carried by the river as a result of the sorting capacity in the main channel and the sediments received from hillslopes. We also analyze the characteristics of the drainage network and the evolution of the index of braiding.

1. THE STUDY AREA

The basin of the River Oja is located in the Ebro basin in the northern half of Spain (Fig. 1). It is laid out in a lengthened form from South to North, and it occupies a

FIG. 1. AREA OF STUDY



surface of 380 $Km.^2$ The river Oja springs in the central area of the Sierra de la Demanda, in the more northwestern massif of the Iberian System. Its drainage area is constituted by both this mountainous territory and the Ebro Depression, of much lower altitude and with little topographical contrasts.

The Sierra de la Demanda is framed by rocks of paleozoical age, specially quartzites, sandstones and slates, all intensely folded and broken (COLCHEN, 1974). The relief is dominated by a summital erosion surface (San Lorenzo, 2262 m), nearly 2000 m of altitude, under which other erosive levels are arranged (LEMARTINEL, 1985). In consequence, water divides appear smoothly rounded; however, the fluvial network has originated very extended and partially regularized slopes, overlapped by a mantle of periglacial screes (ARNAEZ VADILLO, 1987).

The Ebro Depression is considerably younger (Cenozoic), with continental sediments organized in an aureoled figure from the border to the center (conglomerates, sandstones and clays in the area of study). Conglomerates of basin border are of two classes (RIBA, 1955): The oldest of them are well consolidated by calcareous concrete; the modern ones («Santurdejo facies») lack of calcareous concrete and the fine matrix is a mixture of sand and clay that gives little consistence to the deposits. In the Ebro Depression the River Oja has opened a very large valley in which the quaternary sediments (glacis and terraces) occupy the majority of the landscape.

In the mountainous part the climate offers oceanic tendencies variegated by the altitude, with rainfall higher than 700 mm per year and plenty snowfall during the cold season. In the Depression, the climate is mediterranean somewhat continentalized; the rain is concentrated during the intermediated seasons, with less than 600 mm per year.

The River Oja carries out a flow of near 4 $m.^3$ s in Ezcaray, increasing at the end of winter and at the beginning of spring. Despite the lack of direct data, several estimations suggest that it supports floods of great intensity, especially in march and april (GARCIA-RUIZ, GOMEZ-VILLAR and ORTIGOSA, 1987).

2. METHODS

With the object to detect the most important areas in sediment production, we have elaborated a geomorphological map of the basin and we have measured the gravel-size in the channel from the head to the mouth. It is obvious that the lowering of the gradient gives a progressive diminution of gravel-size, but in this tendency several irregularities exist, owing to the arriving of tributaries.

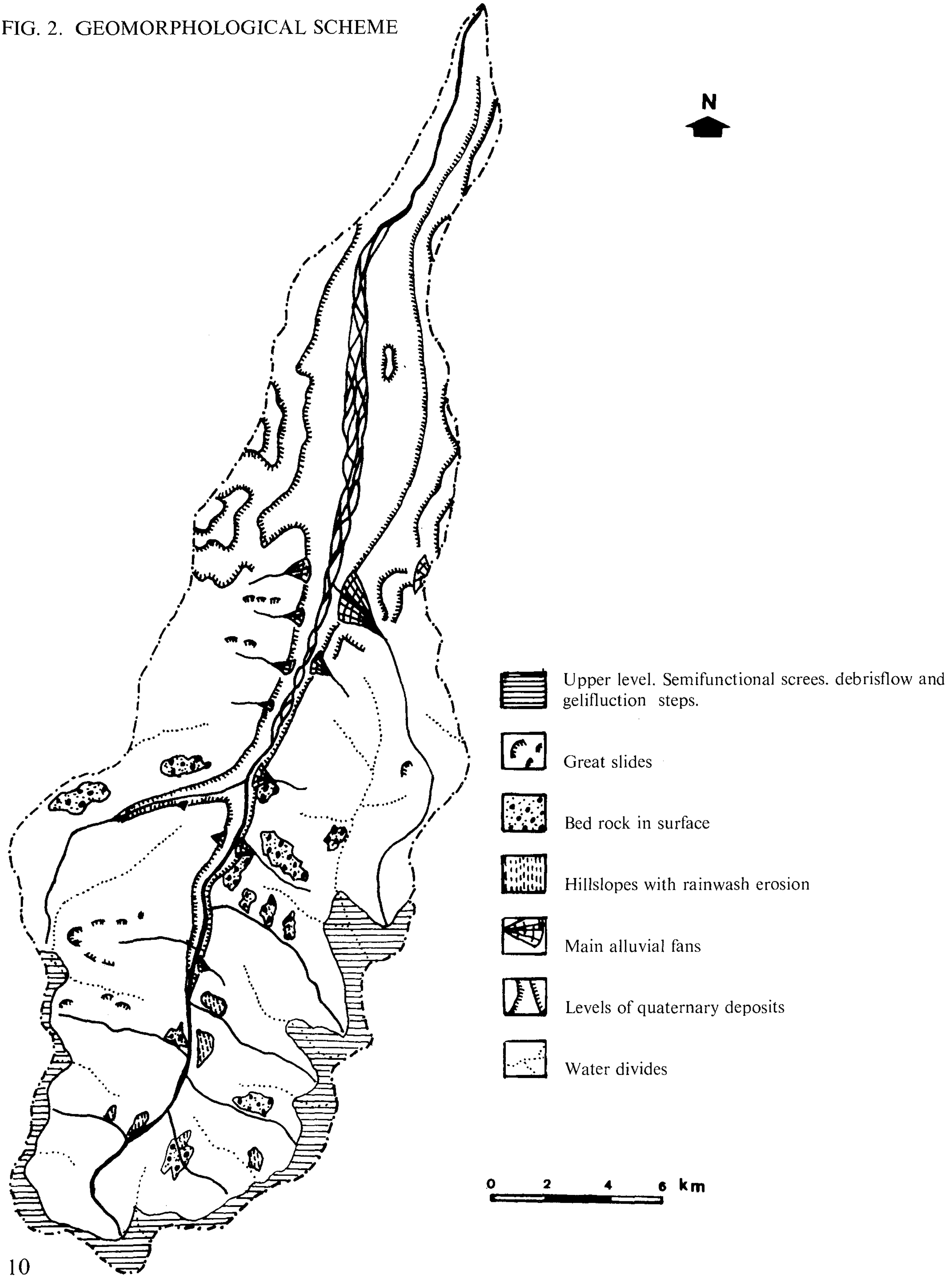
The geomorphological map has been already published at 1:50.000 (GARCIA-RUIZ, GOMEZ-VILLAR and ORTIGOSA, 1987). In this work we only include a global scheme with the most outstanding features of hillslope dynamics (Fig. 2).

For the pebble sampling we have used the method suggested by WOLMAN (1954). In each kilometer of the river we have measured the longest axis of 100 pebbles, in 50 meters of homogeneous channel, one every half meter. For the purposes of this work the data have been managed at a kilometric level (percentils and maximal data).

In the channel we have calculated a braiding index, estimated as the length of all the channels per kilometer of straight distance; it is really a simple sinuosity index that measures de length of all the segments of braided channel. It has been calculated with the aid of aereal photographs at 1: 18.000 scale.

Finally, we have estimated the drainage density for the whole of the basin and for the most important sub-basins, with the aim of detecting the most qualified areas for the evacuation of sediments to the main river.

FIG. 2. GEOMORPHOLOGICAL SCHEME



3. RESULTS

Table 1 shows the evolution of the braiding index along the channel of the River Oja. Such an index is very low at the beginning and it increases from km 12 until it reaches its maximal value between km 30-40; from there it is reduced again, specially near the mouth. This evolution allows us to distinguish three stretches well differenciated by its dynamics and channel pattern:

A. In the head, the River Oja has only a very incised and steepened channel. It is in fact a channel with confined meanders, whose course changes are controlled by the lithology and the intercrossment of faulty lines. It seems to exist an equilibrium between slope dynamics and transport capacity of the River Oja, because the sediments are easily carried out and there is not gravel stockage in the channel.

B. From kilometer 12 on it begins a slight braided channel and the quantity of sediments in the bottom valley increases. An inability of the River Oja to carry out all the sediments is suggested, and at the same time the channel shows greater unstability. In this second strecht the increase of the braiding index is very quick an it is emphasized when the River Oja passes by the basin border conglomerates, already in the Ebro Depression. The channel is notabily widened until it reaches 400 m width downstream Sto. Domingo de la Calzada.

C. Downstream km 40, a new change of dynamics takes place. Central bars as well margins are much more colonized by vegetation. On the other hand, we can see a decreasing of braiding density and a tightening of the channel.

Table 1. *Evolution of braiding index along the channel of the River Oja*

Kilometers	Index of braiding
0 - 9.5	1.2
9.5-12.5	1.06
12.5-15.5	1.45
15.5-22.5	2.01
22.5-29.0	2.92
29.0-32.5	3.98
32.5-41.5	3.95
41.5-48.5	2.48

No doubt, this scheme of fluvial dynamics is closely related with the spatial organization of slope dynamics and with the local capacity of sediment prodution. Figure 2 gives a simple idea of prevailing processes in the whole of the basin. Simplifying the problem we can distinguish three altitudinal levels of hillslope dynamics.

In the lower area of the basin (less than 750 m of altitude), the landscape seems to be dominated by a complex of graded glacis and terraces. Very locally we can meet some active headwaters, settled in declivities between glacis or terraces. In general one can deduce that the slope dynamics of this stretch do not have a great responsability in the present activity of the channel.

Between 750 and 1700 m rainfalls and gradients increase, and the bedrock and talus materials change. It is a level with a great environmental diversity and, then, with a great geomorphological heterogeneity. So, we can distinguish two great groups of processes: Those related with mass movements and those fastened with overland flow. Mass movements lean upon the thick mantle of screes that covers a great part of the slopes of the Sierra. Occasionally these slopes are unstabilized, specialy during the snowmelt, with formation of great slides and little debrisflows. Also this mass movements are relatively frequent in the basin border conglomerates («Santurdejo facies»), in the headwaters and near the drainage axis.

The effects of overland flow appear in slope hillsides, coinciding with little permeable bedrocks. They are local processes that connect directely with the main channel through the tributaries. Sometimes they are active headwaters of ravines or areas affected by wash erosion, showing partly parent material in surface.

Above 1700 m, where the absence of forest is nearly general, the role of ice and snowfall reaches a great importance. In spring soil saturation, frost and dispersed vegetation give a predominance to mass movements of little importance. They are seasonnally active but we think that they are of not great consequences in the main channel. So, we meet many examples of little debrisflows and gelifluction steps. In the highest waterdivides block fields are originated, covering the landscape with a chaotic mantle of pebbles (ARNAEZ-VADILLO, 1985).

In relation with the previous scheme, we have also evaluated the drainage density. In the whole basin, this calculated density is 1.28. In the mountain the mean density is 2.5, according to the slope and little permeable features of bedrock. In the Ebro Depression, with lesser rainfalls and smoother slopes, the mean density is 0.76.

By areas, the main drainage density takes place in the basin border conglomerates, with many ravines of first order. In the head of the River Oja, though the density is also high, it is somewhat lower than in the whole of the montainous sector.

The evolution of gravel-size verifies some of the previous ideas. Non elaborated data point out a decreasing tendency from the head to the mouth (GARCIA-RUIZ, GOMEZ-VILLAR and ORTIGOSA, 1987). At the beginning the pebbles of the channel are of great size; many of them have reached the bed by means of simple gravity from the nearest slopes (what evidences a lack of sorting out). But as the slope decreases, the capacity of transport diminishes and pebbles are progresively each time smaller. The arriving of tributaries, with smaller sorting capacity than the River Oja, explains the existance of peaks in the gravel-size; this is why it is possible to detect the most important areas in sediment production. Figure 3 shows the relations between the distance from the head and the percentil of 75 % of gravel-size; figure 4 describes the relations between distance and maximal values recorded in gravel-size per kilometer. Both graphics assume a simplification of original data, since the values are reduced to kilometrical records, but they apport a very valuable information for our purposes.

In figure 3 it is verified the presence of two points located well above the curve of tendency, corresponding both to km. 12 and 18. Point 12 coincides with the arriving of Menares Ravine in the River Oja; it is a little tributary with important mass movements in its headwater. Point 18 coincides with the arriving of Gilbarrena Ravine, with a very degraded basin by overland flow. From km 40 on all points are located slightly above the curve, proving that several coarse gravels are displaced beyond than what could be expected. This is one of the characteristics of gravel transport in a braided river, owing to its torrentiality.

FIG. 3. RELATION BETWEEN THE DISTANCE AND THE 75 % PERCENTIL OF THE GRAVEL-SIZE

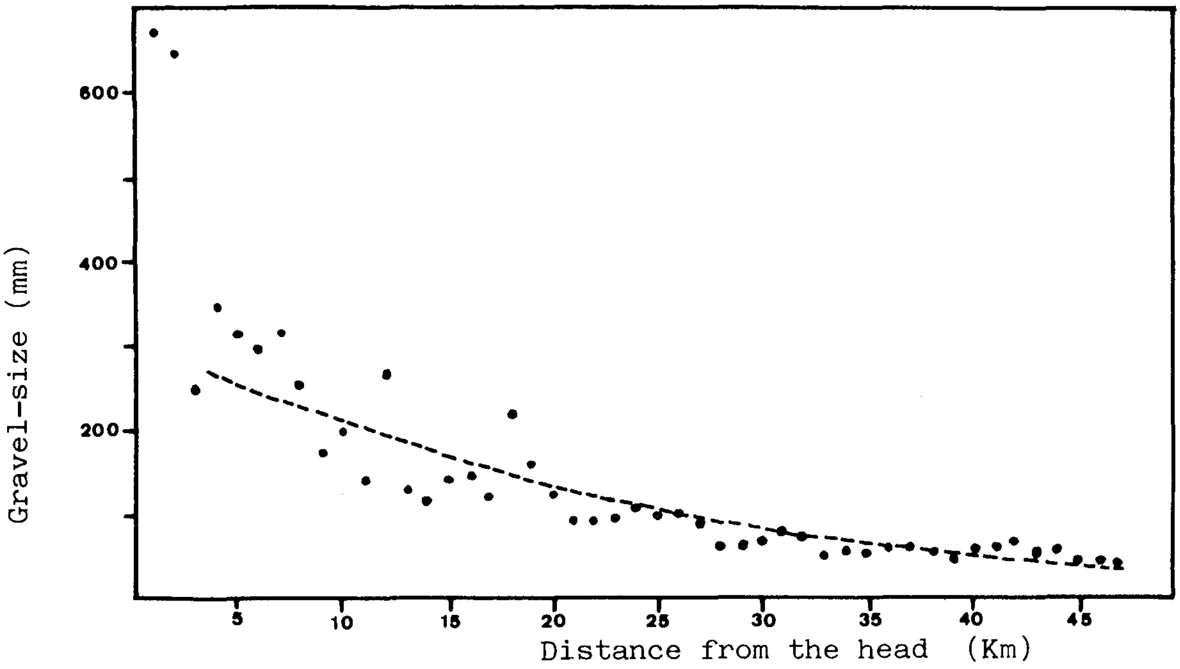
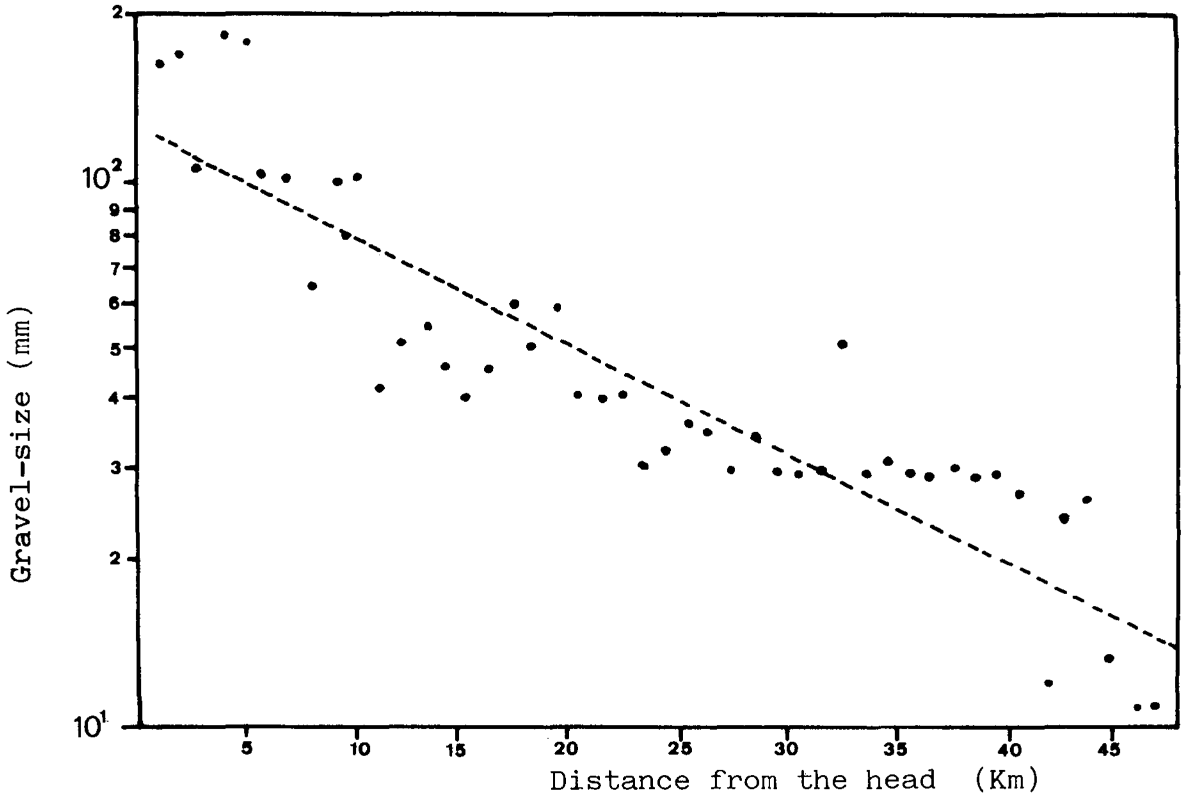


FIG. 4. RELATION BETWEEN THE DISTANCE AND THE MAXIMAL VALUES OF THE GRAVEL-SIZE



In figure 4, using maximal values registered per kilometer and plotting them in a semilogarithmic grafic, we can see two sectors in wich the points are located massively above the fitting straight line. The first of them belongs to the head of the River Oja, with blocks in the channel of a size greater than the available energy could allow: These blocks are of great size and hardly move even in flooding periods. The second of those sectors is located between km 33-34, with a smooth decreasing tendency. It is the sector placed downstream the basin border conglomerates and it also shows the existence of maximal values above the predictable value. We think that this is and evidence of torrential features of the River Oja, consisting in instantaneous displacement of sediments that, once deposited, move again with great difficultly. This phenomenon allows us suppose that the River Oja behaves in a part of the Ebro Depression as a great alluvial fan in wich several greater pebbles are displaced quite a long way during torrential floods. On the other hand it is a new proof of the importance of conglomerates as sediment producers; the arriving of ravines from these conglomerates states an increase of maximal values recorded in the gravel-size.

4. DISCUSSION

The River Oja shows a clear tendency to braiding in a large part of its course with sediment accumulation in the channel. Such sediments are produced by mass movements and by the activity of headwaters in several ravines. Mass movements result essential to explain the gravel stockage in the main channel since they apport sediments in an instantaneous and bulky form and they consequently make difficult its inmediate evacuation by the river; moreover, since they affect to a part of the hillslope, they lack sorting capacity and the channel is invaded by an agglomeration of very heterometrical pebbles. Owing to the momentaneous viscosity of transport environment, these heterometrical pebbles may move further than what the sorting capacity of the River Oja allows; when they are deposited, they find it very difficult to move again, encouraging the sedimentation of other materials and the increase of braiding. SELBY (1981) considers that great slides can refill the valley bottoms partially preventing its downstream displacement. HAYWARD (1980) points out that the passage of sediment clouds its related to the sudden fall of materials in the bed by means of slides near the banks. In Central Pyrenees, GARCIA-RUIZ and PUIGDEFABREGAS (1985) explain the accumulation of sediments in braided rivers by the intense activity of slides in slopes with abundant coarse material.

The headwaters of some ravines also appear as sediment producers, as well the cutting of tributaries in their own bed and the undermining of the nearest banks in periods of great rainfall.

In consequence, we consider that the origin of sediments in the River Oja is local enough, verifying the generaly steady character of the Sierra de la Demanda. The more active areas are the following:

A. Some ravines of the Sierra de la Demanda, especially Gilbarrena and Menares; in the first case overland flow processes dominate and, in the second, mass movements of the headwater. The impact of both is detected in figure 3.

B. The basin border conglomerates, very unstable owing to its lack of consistency and also affected by a high drainage density. The fact is that all the ravines arriving to the River Oja from this area build alluvial fans of diverse size and present activity.

The most elevated zones of the basin, however, seem to be very stable and with little capacity to transport sediments to the channel. Likewise, the lower area of the basin in now poorly active and the ravines that drain the Ebro Depression show limited activity.

A close connection is clearly confirmed if we related sediment production areas with the evolution of braiding. Braiding begins when the hillslopes drained by the River Oja are active from a geomorphological point of view; it increases progresively with the arriving of more unstable tributaries and it reaches its maximal value a little downstream the basin border conglomerates. In the final kilometers, the distance from the source-area of sediments implies a decrease of braiding. Obviously other factors can be of influence (See GARCIA-RUIZ, GOMEZ-VILLAR and ORTIGOSA, 1987) but slope dynamics is in a great part responsible for the channel pattern adopted by the River Oja all along its course.

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