The Effects of Damming and Recent Climatic Changes on the Sediment and Water Discharge of the Ebro River (Northwestern Mediterranean)

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The Ebro River is one of the most important fluvial systems that discharge into the Northwestern Mediterranean Sea. During the last few centuries this fluvial system has been greatly affected by human activities. Deforestation of its drainage basin became very intense from the 15^{th} century onwards, making the deltaic system prograde very rapidly. Construction of irrigation systems became important at the end of the 19^{th} century and the beginning of the 20^{th} century and in addition, many dams have also been built during this century. These facts have dramatically changed the sediment dynamics and the hydrodynamics of this fluvial system. The area most affected by this changes is the lower part of the river and especially the delta and the river mouth, where the marine-fluvial interaction controls the evolution of the delta.

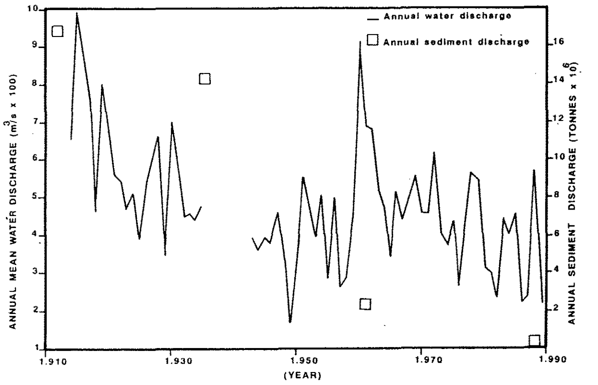

Fig.1. Annual Water and sediment discharge of the Ebro River during the 20^{th} century

The water discharge of the Ebro river is quite irregular during the year. The annual distribution of water discharge in the lower part of the river shows that the higher values occur between November and March and the lower values in summer. During this century the annual mean water discharge of the Ebro River has been very irregular. Maximum mean water discharge was 992 m^3/s in 1915 and the minimum was 165 m^3/s in 1949. The mean distribution shows a decreasing trend from 1914 to the present with some stages of high water discharge. These stages correspond to 1915 and 1960. Another stage may have taken place in 1937 when a strong flood led to a change in the location of the river mouth. Unfortunately there are no data for the end of the thirties. The decreasing trend in the annual water discharge has been quite continuous from 1960 to the present. The eighties have been especially dry years. In 1982, 1986, 1987 and 1989 the mean was lower than 250 m3/s. The decreasing trend in annual mean water discharge can be attributed to the human management of the river water and to climatic changes. Dams have also contributed to mitigate the river floods. Floods of more than 3000 m3/s took place before the construction of the dams, but after the regulation of water discharge induced by the dams, these big floods have ceased to occur.

Historical data allow the estimation of sediment discharge in the late 19^{th} century. In 1891, before the construction of the dams, suspended load transported by the river was about 25×10^6 tons per year. Like the water discharge, the transport of suspended sediment without river damming was quite irregular during the year. During the higher water discharge floods, the river could transport more than 10^6 Tm/day. Between 1906 and 1930, some significant dams (200 Hm^3) were built in the upper part of the Segre River and several small capacity reservoirs (0.3-28 Hm^3) were built in some of the Ebro River tributaries. The average amount of suspended sediment transported by the river decreased to 17×10^6 tons per year in 1911 and to 14×10^6 tons per year in 1935. A really significant reservoir was not constructed until the forties, when the Ebro dam (540 Hm^3) was built in the upper part of the river. During the forties and the fifties several reservoirs with a capacity ranging from 50 to 200 Hm3 were constructed. In 1959 another important dam, the Yesa dam (470 Hm^3) was located in the upper part of the Aragon River (one of the most important tributaries of the Ebro River). At the beginning of the sixties, the amount of suspended sediment discharged by the river was 2.2×10^6 tons/year. The largest dam in the Ebro system (the Mequinenza dam) was built in the lower part of the river in 1966. The Mequinenza dam has a capacity of more than 1000 Hm^3. In 1969 the Ribarroja dam (136 Hm^3) was built a few kilometers downstream of the Mequinenza dam. In 1968 another important dam was constructed in the Cinca River, the Mediano dam, whose capacity is 436 Hm^3. During the eighties the Ebro river discharged only between 120.000 and 150.000 tons per year (Fig.1). This means that at the present time the Ebro River is discharging into the Mediterranean less than 1% of the suspended sediment that this river discharged into the sea before the construction of the dams (Palanques, 1987; Palanques et al., 1990).

This huge reduction of the sediment input is mainly the result of the accumulative sediment retention in each of the dams built along the Ebro river and its tributaries and it is also the result of the location of the Mequinenza and Ribarroja dams. These dams are located only a few kilometers upstream of the delta and they retain more than the 75% of the suspended sediment input and the totality of the bed load input that they receive (Palanques, 1987, Palanques et al., 1990). The decrease of the river water discharge also contribute to the reduction of the river sediment discharge. Moreover, dams prevent the big floods that could transport huge amount of sediment to the sea. At present, the Ebro river discharges mainly very fine sediment to the marine environment, the bed load transported along the lower part of the river is insignificant and the Ebro delta coast receives practically no sand sediment supplies from the river so the action of the marine processes on the delta coast dominates the present evolution of the delta. It is not possible to interpret the geological record of the recent Ebro sedimentary deposits from present day river conditions.

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Biofaciès Margino-Littoraux de la Méditerranée Occidentale (Baléares et Valence-Alicante-Murcie) Espagne

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En Méditerranée Occidentale, tant sur l'Ile de Majorque que sur le littoral péninsulaire (Murcie, Alicante et Valence), d'importantes formations lacustres du Néogène-Quaternaire offrent d'intéressants biofaciès margino-littoraux incluant des organismes dont les biotopes oscillent entre les eaux douces et les eaux supersaturées.

Pour l'Ile de Majorque préorogénique (Burdigalien inférieur) l'existence de lagunes paraliques est confirmée par la présence de biocénoses chaudes et euryhalines, alors que le lacustrisme post-orogénique des Baléares doit être rapporté aux processus régressifs finimiocènes et surtout à ceux dépendant de la grande crise messinienne de salinité dans toute la Méditerranée (COLOM, 1985).

Le sondage, de 350 m de longueur, à l'intérieur de l'Albufera de Alcudia (Majorque) nous offre une paléo-biologie tortono-messinienne, dont le caractère nettement marin (*Marginulina costata, Cibicides pseudoungerianus*, etc. et dans les formes planctoniques *Globorotalia mediterranea, Turborotalia acostaensis, Globigerinoides obliquus*, etc.) cède la place à des niveaux riches en espèces littorales (*Ammonia beccarii, Florilus boueanus*, etc.). Sur ces faciès, repose un niveau de Charophytes, Ostracodes euryhalins et cristallisations de gypse syngénétique, typique d'un milieu polyhalin et tendant à une haute salinité.

Cet épisode paralique finimessinien, régressif et interinsulaire, atteint 30 m de puissance sédimentaire et paraît contemporain de l'intervalle entre la fermeture des "canaux" bétique et morafricain et l'ouverture origopliocène du Détroit de Gibraltar.

C'est entre -183 et -110 m du sondage qu'apparaît une faune planctonique riche en Foraminifères, avec plus de 60 espèces parmi 6000 individus (MATEU, 1982) qui indique l'incursion d'une microfaune atlanto-ibéro-africaine (*Sphoeroidinellopsis seminulus, Globorotalia margaritae, Globorotalia puncticulata*, etc.) à travers le nouveau Gibraltar.

Dans le Pliocène médio-supérieur, et précisément pendant le Plaisancien, se consolide l'écosystème lacustre, marginolittoral de Majorque, avec *Ammonia tepida, Chara* sp. et *Hydrobia* sp. etc. qui, tant dans le marais d'Alcudia que dans les autres zones humides de la moitié sud de l'île est lié à la fluctuation quaternaire de la ligne de côte au colmatage progressif alluvial du "canal central de Majorque" et à la régulation de ces aquifères.

Les zones lacustres de Majorque (Baléares) aussi bien que celle de Valence-Alicante-Murcie se trouvent dans les rades d'âge Postmiocène, sur un substrat Méso-cénozoïque, plissé pendant l'orogénie alpine, avec des plissements et des failles d'orientation bétique (NE-SO).

Ces biofaciès margino-littoraux des îles de la Péninsule, évoquent non seulement les anciens écosystèmes "Lago Mare", comparables aux actuels de la Mer Noire (TUFESCU, 1974), mais aussi les unités Pleisto-holocènes du littoral de Valence (Pego), Murcie (Mar Menor) et Majorque (Albufera de Alcudia, Salobrar de Campos) ; malgré le tectonoglacioeustatisme quaternaire, (RIO *et al.*, 1987 etc.), tous ont des associations de biocénoses margino-littorales méditerranéennes (LEVY, DUPRE *et al.*, 1988, MATEU, 1989, etc.)

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