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Longshore Variation of Grain Size Distribution along the Coast of the Rhône Delta, Southern France: A Test of the "McLaren Model"

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ABSTRACT

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Twenty nine beachface samples from the Rhône delta were collected and analysed to assess the application of the sediment transport model devised by McLaren and Bowles (1985). According to this model, in the direction of longshore transport, successive sediment samples should become either coarser, better sorted, and more positively skewed, or finer, better sorted, and more negatively skewed. However, the Rhône delta beachface sediments tend to get finer and more poorly sorted in the longshore transport direction, and skewness exhibits no significant trend. The main reasons for the disagreement between the actual transport path along the Rhône delta coast, and that predicted by the model of McLaren and Bowles is the fact that several assumptions underlying the model are not valid in the nearshore environment. Therefore, the use of the model in determining transport paths in the nearshore zone is limited.

ADDITIONAL INDEX WORDS: *Grain size distribution, grading, longshore sediment transport, Rhône.*

INTRODUCTION

The net longshore sediment transport direction is an essential factor in coastal planning, management and research. However, the net littoral drift direction is not easily obtained since, unlike uni-directional fluvial transport, littoral drift is often bi-directional. In the nearshore zone, the longshore sediment transport direction is dependent on wind, waves and tide, which generally vary throughout the year. Therefore a thorough coastal study is necessary to acquire the dominant longshore transport direction. Additional evidence may be obtained from the shoreline configuration in the vicinity of coastal structures (*e.g.*, jetties, groyns) and examination of the coastal geomorphology (*e.g.*, spits).

In coastal areas where man-made structures are absent and the coastal geomorphology does not indicate a dominant longshore sediment transport direction, an expensive and time consuming coastal study is needed to acquire the littoral drift direction. In such cases a study may be aided if the sediment transport direction is reflected in the longshore variation of the beach sediment texture.

Previous studies have shown that beach sediments become increasingly finer and better sorted in the direction of longshore sediment transport (Combellick and Osborne, 1977; Ramsey and Galvin, 1977; Self, 1977; Trask and Hand, 1985, and many others), although a downdrift coarsening has also been observed (*e.g.*, Schalk, 1938; McCave, 1978).

Recently, McLaren (1981) and McLaren and Bowles (1985) devised a model which uses spatial trends in sediment textures to determine the sediment transport direction. In the model (henceforth referred to as the "McLaren model"), the distributions of sediment in transport are related to their source by a sediment transfer function, which defines the relative probability that a grain within each particular class interval will be eroded and transported. McLaren and Bowles (1985) demonstrate that, depending on the energy level of the transfer function, in downstream direction,

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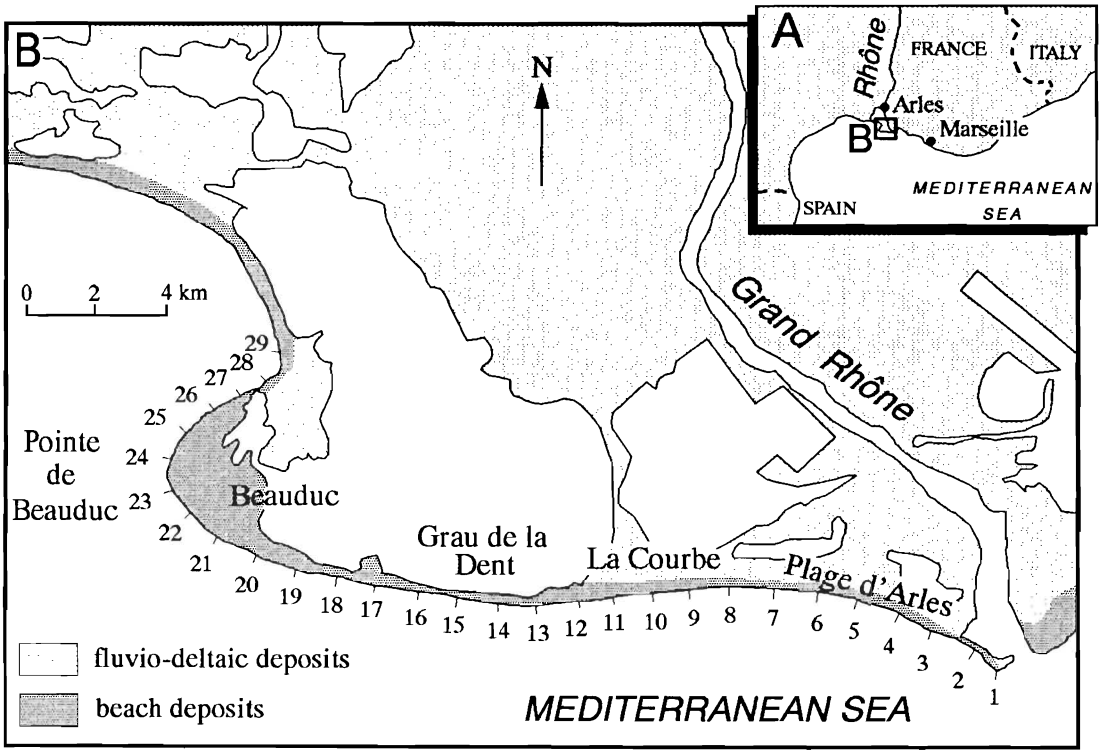

Figure 1. Region of investigation (A) and the sample locations (B).

sediments become either finer, better sorted, and more negatively skewed ("Case B transport"), or coarser, better sorted, and more positively skewed ("Case C transport"). In both cases the energy level decreases in downstream direction, but Case C transport is initially characterized by larger flow rates than Case B transport. The McLaren model has now been applied widely (*e.g.*, McLAREN and LITTLE, 1987; McLAREN and POWYS, 1989).

In this paper, the validity of the McLaren model for the sediment transport by longshore currents is scrutinized. Beachface samples from the Rhône delta were collected over a distance of 30 km at one km intervals, and the textural properties of these samples were analysed. The longshore sediment transport direction in this coastal area is known, and a comparison with the model will demonstrate that the model is not universally applicable in the nearshore zone.

ENVIRONMENTAL SETTING

The River Rhône has its source in the Swiss Alps and discharges in the Mediterranean Sea. The Rhône delta ("Camargue") begins some 50 km from the coast at Arles, where the river bifurcates to form the Petit and the Grand Rhône (Figure 1a). The study area is confined to the shoreline between the mouth of the Grand Rhône and the sheltered area of Beauduc, and is approximately 30 km long (Figure 1b).

The coast of the Rhône delta is characterized by low tidal amplitude (0.2 m), low wave energy (modal significant wave height 1.0 m; modal wave period 5–6 sec) and prevailing offshore winds (BLANC, 1981). In the nearshore zone, generally two or three nearshore bars are present. The dominant deep water wave direction offshore the Camargue coast is south-south-east (BLANC, 1981). Taking into account the orientation of the coastline, the net longshore current direction between the mouth of the Grand Rhône and Pointe de Beauduc is westward (KRUIT, 1955; BLANC, 1981; ELFRINK and MASSELINK, 1989). Apart from the promontory just west of the mouth of the Grand Rhône, the entire coastline between the Grand Rhône and Pointe de Beauduc is eroding. Part of

the eroded beach material is transported westward by longshore currents and is eventually deposited at Beauduc in the form of wave-built ridges parallel to the coastline, causing a significant coastal advance (KRUIT, 1955; ELFRINK and MASSELINK, 1989). These spits tend to expand to the northeast and thus demonstrate that their sediments passed Pointe de Beauduc (KRUIT, 1955). It is concluded that for the study area, longshore sediment transport is from the mouth of the Grand Rhône to the sheltered area of Beauduc.

GRAIN SIZE ANALYSIS

Methods of Sampling and Analysis

Twenty nine beach samples were collected at a one kilometer spacing from the mouth of the Grand Rhône to Beauduc (Figure 1b). Sand samples were taken at mid-beachface position, since beaches are best typified by mid-beachface sands (BASCOM, 1951; EMERY, 1960). Because this study was concerned with the net sediment transport direction on a regional scale, the top few centimetres of the beachface were sampled. No attempt was made to sample individual laminae because the characteristics of a lamina may be the result of effects that are too local for effective comparison on a more regional scale (MCLAREN, 1981). Data collection spanned two days in May, 1988.

The samples were processed in a random sequence. A representative 30 to 50 g split from each bulk sample was obtained. Each sand sample was treated with hydrogen peroxide and hydrochloric acid to remove the organic matter and calcium carbonate, respectively. The samples were dried and then sieved for 20 min using a 1/4 phi screen interval. Summary statistics were determined by calculating the first three moments of the grain size distribution, yielding the mean, the variance and the skewness, respectively (LEWIS, 1984, p. 74). The square root of the variance gave the sorting of the distribution.

Results

The mean grain size of the beachface sediment ranges from 2.5 phi (0.18 mm) to 1.6 phi (0.33 mm). The sand is well to very well sorted (0.4 to 0.1 phi), and the skewness ranges from strongly fine-skewed to strongly coarse-skewed (−0.6 to 1.0) according to the classification of FOLK (1974). In general, the beachface samples tend to become finer and more poorly sorted from the Grand Rhône to Beauduc (Figure 2). The skewness exhibits large fluctuations from sample 1 to 29. A linear regression analysis performed on the grain size, sorting and skewness trend, yields correlation coefficients (r^2) of 0.71, 0.44 and 0, respectively. A test of correlation (DAVIS, 1986, pp. 66–67) shows that the grain size and sorting trend are both significant at the 0.5% level.

Following MCLAREN and BOWLES (1985), a Z-test (SPIEGEL, 1961) was used to determine the sediment transport direction by examining all possible pairs in a sample suite. If one sample is compared with another with respect to their mean size, sorting and skewness, eight possible trends exist; compared to sample 1, sample 2 may be (1) finer (F), better sorted (B) and more negatively skewed (−); (2) coarser (C), more poorly sorted (P) and more positively skewed (+); (3) F, B, +; (4) F, P, −; (5) F, P, +; (6) C, P, −; (7) C, B, −; or (8) C, B, +. For each of these trends the probability of random occurrence is p = 0.125. According to the McLaren model there are two trends indicative of transport, namely F, B, − and C, B, +, and a Z-test can be used to determine whether the number of occurrences indicating sediment transport exceeds the random probability of 0.125. The following hypotheses were tested:

H_0: $p \leq 0.125$, there is no preferred direction
H_1: $p > 0.125$, transport is occurring in a preferred direction.

H_1 is accepted if

$$Z = \frac{x - Np}{\sqrt{(Npq)}} > 2.33 \text{ (1\% level of significance)}$$

where x = observed number of pairs indicating a particular transport direction, N is the total number of possible pairs (with 29 samples N = 435), p = 0.125 and q = 0.875. The results of the statistical analysis are given in Table 1.

It appears that only the coarser, better sorted, and more positively skewed trend from Beauduc to the mouth of the Grand Rhône is significant. Thus, according to the McLaren model, sediment is transported from Beauduc to the Grand Rhône. The transport is initially characterized by large flow rates, and energy level decreases downstream (Case C transport of MCLAREN and BOWLES, 1985).

DISCUSSION AND CONCLUSIONS

If the McLaren model is applied to the 29 beachface samples of the Rhône delta, a sediment

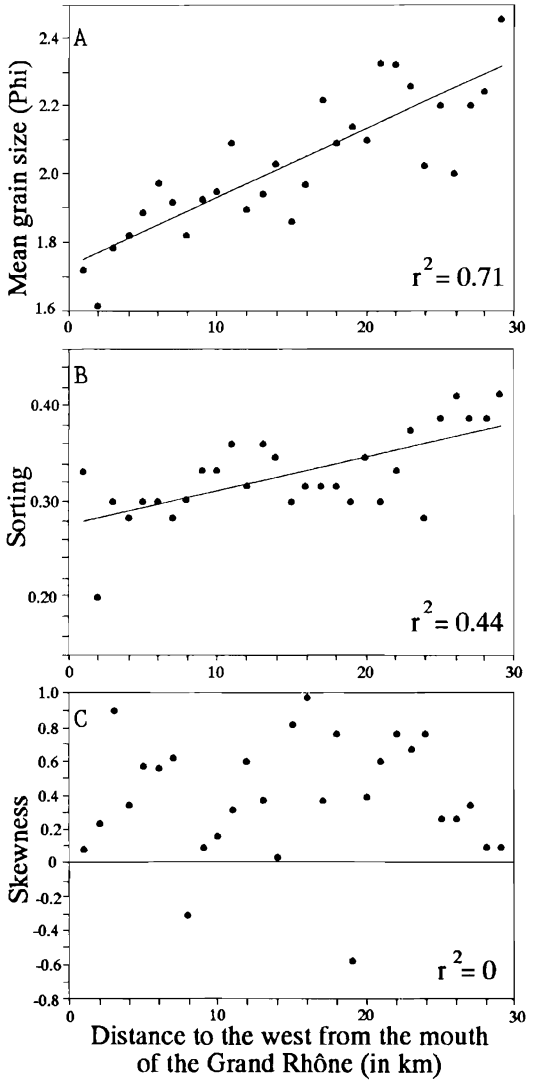

Figure 2. Plot of the mean grain size (A), sorting (B) and skewness (C) as a function of distance in km to the west of the mouth of the Grand Rhône. Since both the size and the sorting trend are significant at the 0.5% level, the associated lines of best fit are given. Skewness does not exhibit any significant trend and hence the line of best fit is not plotted.

Table 1. *Summary of the number of pairs of the Rhône delta samples (N = 435).*

	Grand Rhône-Beauduc	Beauduc-Grand Rhône
Finer, better sorted, and more negatively skewed	x = 22 Z = −4.69	x = 9 Z = −6.58
Coarser, better sorted and more positively skewed	x = 17 Z = −5.42	x = 145 Z = 13.14*

*Significant at the 1% level

transport direction is deduced which is opposite to the actual longshore sediment transport direction. According to the model, in downstream direction the sediment should become either finer, better sorted, and more negatively skewed, or coarser, better sorted, and more positively skewed. However, in the Rhône delta the beachface sediment tends to become finer and more poorly sorted in downstream direction, and skewness exhibits no significant trend.

It is suggested that the disagreement between the actual and the predicted transport direction is due to three major assumptions of the McLaren model being violated when used in the nearshore zone to predict longshore sediment transport direction. Firstly, the model assumes uni-directional flow, whereas longshore transport is often bi-directional. Secondly, the sediment in transport is supposed to be derived from one source. On a beach, the sediment may be derived from several sources including rivers, eroding beaches, dunes, shoreface. Thirdly, the McLaren model assumes that the net sediment transport is the primary factor in causing textural trends. However, on a beach there are also other factors which influence the sediment characteristics of beach sands. For example, the influence of wave energy level has been shown by numerous researchers (*e.g.*, CHAUDRI *et al.*, 1981; BRYANT, 1982; CHAUHAN *et al.*, 1988) and cross-shore sediment transport processes resulting in beach erosion or accretion have also been shown to have an important influence on the beachface sediment (*e.g.*, SONU, 1972; CHAUHAN, 1989; DUBOIS, 1989).

It is therefore concluded that the use of the McLaren model in determining the longshore sediment transport direction in the nearshore zone is limited.

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□ RÉSUMÉ □

Pour tester le modèle de transport sédimentaire de McLaren et Bowles (1985), on a prélevé et analysé 29 échantillons du delta du Rhône. Selon ce modèle, les échantillons de sédiments deviennent plus grossiers, mieux triés et aplatis négativement dans le sens du transport parallèle à la côte. Pourtant, les sédiments de la face maritime du delta du Rhône tendent à être plus fins et moins bien triés en direction du transport parallèle à la coôte, tandis que l'aplatissement ne présente aucune tendance significative. La principale cause de ce désaccord avec le modèle prédit par McLaren et Bowles vient du fait que plusieurs postulats sous jacents au modèle ne sont pas valides dans l'environnement prélittoral. L'utilisation d'un modèle pour la détermination des champs de transport dans la zone prélitorale est donc limitée.—*Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montrouge, France.*

□ RESUMEN □

En el delta del Ródano se colectaron y analizaron 29 muestras del frente de playa para aplicar y evaluar el modelo de transporte de sedimentos desarrollado por McLaren y Bowles (1985). De acuerdo a este modelo, los sucesivos muestreos de sedimentos deberían ser, ya sea muy gruesos, con una buena dispersión y positivamente asimétricos, o muy finos, con buena dispersión y negativamente asimétricos.

Sin embargo, los sedimentos del frente de playa del delta del Ródano tienden a ser más finos y con una pobre dispersión en dirección de la deriva litoral y la asimetría no presenta una tendencia significativa. Las razones principales para esta discordancia entre el camino del transporte real a lo largo de la costa del delta del Ródano y la predicha por el modelo de McLaren y Bowles, es

el hecho de que varias de las suposiciones fundamentales del modelo no son válidas en los ambientes cercanos a la costa. Por lo tanto, este modelo es de uso limitado para determinar la dirección del transporte en las zonas costeras.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*

□ ZUSAMMENFASSUNG □

Neunundzwanzig Strandoberflächenproben des Rhône-Deltas wurden analysiert, um die Anwendung des Sedimenttranport-Modells von McLaren and Bowles (1985) zu überprüfen. Dieses Modell besagt, daß in der Richtung des küstenparallelen Transportes die Sedimente allmählich entweder grobkörniger werden, schlechter sortiert und mit einem positivem Schiefewert ausgestattet sind oder allmählich feinkörniger werden, besser sortiert sind und einen negativen Schiefewert besitzen. Es zeigt sich aber, daß die Oberflächensedimente der Strände im Bereich des Rhône-Deltas in der Richtung des küstenparallelen Transportes tendenziell feinkörniger werden und eine schlechtere Sortierung aufweisen. Gleichzeitig zeigt der Schiefewert keinen eindeutigen Trend. Die Hauptgründe für die Nichtübereinstimmng zwischen aktuellem Transportweg entlang der Küste des Rhône-Deltas und dem durch das Modell von McLaren und Bowles vorausgesagten Weg sind darin zu suchen, daß mehrere Annahmen des Modells im küstennahen Bereich keine Gültigkeit besitzen. Aus diesem Grund kann man bei der Bestimmung von Transportwegen in der küstennahen Strandzone von dem Modell nur begrenzt Gebrauch machen.—*Ulrich Radtke, Geographisches Institut, Universität Düsseldorf, F.R.G.*