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Sediment transport patterns determined from grain size parameters: Overview and state of the art

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Abstract

Grain size trends have been applied in many diverse sedimentary environments to determine sediment transport paths, generally coinciding with information from tracer studies, current measurements and the orientation of sedimentary structures. The different methods proposed to date are critically analysed and compared with reference to recent field studies. It is concluded that the two-dimensional methods produce comparable results and may in fact complement each other.

In spite of the advances, several problems still exist, which include the sampling method and density, the choice of trend types, the relative weight of grain size parameters and the interpretation of results. These are discussed together with possible solutions.

Keywords: Sediment trend analysis; STA; Grain size trends; Sediment transport

1. Introduction

Grain size trends seem to be a natural result of sediment transport processes (Krumbein, 1938; Russell, 1939; Swift et al., 1972; Stapor and Tanner, 1975; McCave, 1978; Harris et al., 1990), which is primarily related to the effects of abrasion and selective sorting. Early studies suggested that the grain size decreases in the direction of transport (Pettijohn and Ridge, 1932; Plumley, 1948; Yeakel, 1962; Mothersill, 1969; Pettijohn et al., 1972; Self, 1977) but other investigations sometimes indicated the opposite (McCave, 1978; Nordstrom, 1981, 1989). Because of this uncertainty, later investigators preferred a combination of grain size parameters, such as the mean size D_μ, sorting σ, and skewness Sk (McLaren, 1981). McLaren and Bowles (1985), based on a rigorous examination of the processes involved, concluded that sediments always become better sorted downstream whereas D_μ can either increase together with a decrease in Sk or decrease together with an increase in Sk. Gao and Collins (1991) argued from theoretical considerations that deposits can also become coarser and more negatively skewed in the downstream direction whereas Self (1977) reported deposits becoming finer and more positively skewed along the transport path. Of the eight possible combinations, four types of granulometric trends seem to dominate in nature. Expressed in terms of ϕ units (Folk and Ward, 1957), these are:

$$\begin{aligned} &\text{Type 1}: \sigma_1>\sigma_2; D_{\mu1}<D_{\mu2}; \text{Sk}_1>\text{Sk}_2 \\ &\text{Type 2}: \sigma_1>\sigma_2; D_{\mu1}>D_{\mu2}; \text{Sk}_1<\text{Sk}_2 \\ &\text{Type 3}: \sigma_1>\sigma_2; D_{\mu1}>D_{\mu2}; \text{Sk}_1>\text{Sk}_2 \\ &\text{Type 4}: \sigma_1>\sigma_2; D_{\mu1}<D_{\mu2}; \text{Sk}_1<\text{Sk}_2 \end{aligned} \quad (1)$$

with the subscripts 1 and 2 indicating sampling sites 1 and 2 along the direction of transport.

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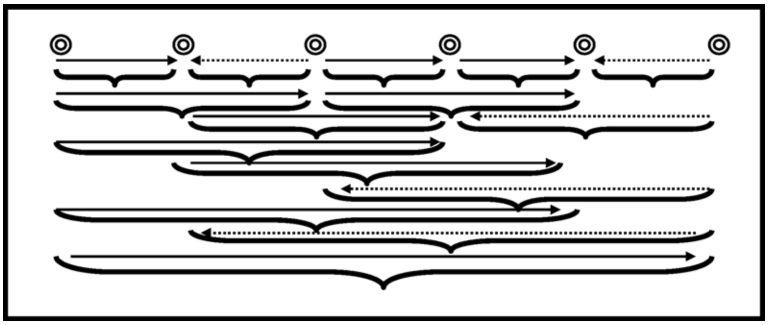

Fig. 1. The McLaren and Bowles (1985) method compares all possible sample pairs located along the sampling lines. The trends are statistically analysed to determine the dominant direction along each survey line.

Using these trends, several methods have been developed to define sediment transport paths. These techniques have been applied to engineering and dredging schemes (e.g. McLaren and Powys, 1989), environmental studies (McLaren et al., 1981; McLaren, 1983, 1984; McLaren and Little, 1987; McLaren et al., 1993a,b; Uriarte et al., 1998; Pascoe et al., 2002), and in general sedimentological investigations (McCave, 1978; Nordstrom, 1981, 1989; McLaren and Collins, 1989; Zhang and Zhu, 1989; Gao and Collins, 1992, 1994; Gao et al., 1994; Vanwesenbeeck and Lanckneus, 2000; Mallet et al., 2000; Carriquiry et al., 2001; Ríos et al., 2002; Poizot et al., 2006).

2. Methodology

2.1. Analysis of grain size distributions

Grain size parameters such as the mean, sorting and skewness are usually obtained from analyses of the grain size distributions by sieve or settling techniques. Sediment sieve size (D_v) is construed as the diameter of the largest sphere that would pass through the retaining sieve whereas the fall or settling size (D_s) is considered to be the diameter of a quartz-density sphere with the same settling velocity as the sediment particle. Both methods have advantages and drawbacks and may produce significantly different results, although the settling diameter D_s is probably a better measure of size in terms of sediment dynamics (Le Roux, 2005).

The grain size parameters are commonly determined from the grain size distribution expressed in ϕ units ($\phi = -\log_2 D$). A cumulative frequency curve is plotted using an arithmetic scale on the abscissa for the size classes and either an arithmetic or probability scale on the ordinate for the cumulative weight frequency, which sums to 100%. Graphical or moment methods are then used to calculate the grain size parameters.

Very little work has been done on the influence of different methods for determining the grain size parameters on spatial sediment trends. However, because trends are defined by the relative values among data stations, rather than their absolute values, the specific method employed is probably of minor importance. Hill and McLaren (2001) determined two sets of descriptive statistics, one derived from log-hyperbolic curves fitted to grain size data and the other computed using a model-independent method, to generate transport vectors in four areas where the transport direction was known unequivocally. Both sets correctly predicted the direction of transport with essentially the same statistic significance. They concluded that the use of log-hyperbolic distributions provides no particular advantage in the analysis of grain size trends.

2.2. Analysis of sediment transport trends

Earlier attempts to define sediment transport patterns based on grain size parameters followed an essentially one-dimensional approach (e.g. McCave, 1978; McLaren, 1981; McLaren and Bowles, 1985). Some statistical modifications to this approach were subsequently proposed by Lucio et al. (2004). Gao and Collins (1992) introduced a two-dimensional treatment of grain size data based on a modification of the McLaren (1981) method, comparing two data stations at a time. Le Roux (1994b,c) proposed an approach based on the comparison of groups of five stations at a time, using a modified vector analysis procedure to determine the transport vectors. Asselman (1999) modified the Gao and Collins (1992) method and implemented it in a Geographical Information System together with geostatistical analysis. Rojas et al. (2000) fitted planes to a central station and two neighbouring stations at a time, employing the dip direction of all the generated planes around the central station to define vectors and subsequently averaging the vectors around the